Warfighter Integrated Physical Ergonomics Tool Development

Needs Analysis and State of the Art Review

Prepared By:
David W. Tack and Kent W. McKee
Humansystems® Incorporated
111 Farquhar Street
Guelph, ON N1H 3N4

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David W. Tack and Kent W. McKee

Human*systems*® Incorporated
111 Farquhar Street
Guelph, ON N1H 3N4

Project Manager:

David W. Tack
(519) 836-5911

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Defence Research and Development Canada - Toronto
1133 Sheppard Avenue West
Toronto, ON, M3K 2C9

Project Scientific Authority:

Linda Bossi, CD
416-635-2197

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Abstract

This report presents methods and results from the front-end analysis for the “Preliminary Development of Integrated Physical Ergonomics Modeling Tools to enhance Warfighter Effectiveness” Applied Research Project (ARP). The objectives of the front-end analysis were to identify stakeholder needs for integrated physical modeling tools (users and workspace), and to survey the state-of-the-art and acquire the most suitable, affordable, available tools for measuring and modeling the physical aspects of Canadian warfighters.

For the stakeholder needs analysis, DND and industry stakeholders were consulted for current warfighter system and transport vehicle projects. The state-of-the-art review of current physical ergonomics tools was conducted by reviewing product and scientific literature. Tool developers and manufacturers were contacted for technical details and pricing information. Tools were categorized by function and tool groups within each function. Product details were compiled and a summary description of each tools and their pros and cons was derived.

Executive Summary

Warfighter Integrated Physical Ergonomics Tool Development

David W. Tack and Kent W. McKee, Human*systems*® Incorporated; DRDC-RDDC-2015-C227; Defence R&D Canada – Toronto; March 2011.

The Canadian Department of National Defence (DND) requires knowledge of the impact of clothing and personal equipment on human biomechanics, task performance, endurance, mobility, vulnerability, and survivability. Systematic modeling of these factors is needed for decision-making on future warfighter systems, and more up-to-date data are needed to more accurately specify workspace designs and user fit accommodation requirements.

This report presents methods and results from the front-end analysis for the "Preliminary Development of Integrated Physical Ergonomics Modeling Tools to enhance Warfighter Effectiveness" Applied Research Project (ARP). The objectives of the front-end analysis were to identify stakeholder needs for integrated physical modeling tools (users and workspace), and to survey the state-of-the-art and acquire the most suitable, affordable, available tools for measuring and modeling the physical aspects of Canadian warfighters.

For the stakeholder needs analysis, DND and industry stakeholders were consulted for current warfighter system and transport vehicle projects. Their requirements were made known for integrated physical ergonomics data capture, analysis and modeling tools. Consultation included DRDC scientists, project and matrix staff from DGLEPM, DLR, and representatives from air and maritime platform acquisition projects.

The state-of-the-art review of current physical ergonomics tools was conducted by reviewing product and scientific literature. Tool developers and manufacturers were contacted for technical details and pricing information. Tools were categorized by function and tool groups within each function. Product details were compiled and a summary description of each tools and their pros and cons was derived. As far as possible, we have tried to be comprehensive and representative in the listing of candidate technologies and products.

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1. Background

The Canadian Department of National Defence (DND) requires knowledge of the impact of clothing and personal equipment on human biomechanics, task performance, endurance, mobility, vulnerability, and survivability. Systematic modeling of these factors is needed for decision-making on future warfighter systems, and more up-to-date data are needed to more accurately specify workspace designs and user fit accommodation requirements. Increasing evidence has shown that the available anthropometric data for the Canadian Forces (CF) no longer represents the current size and shape of Canadian Forces (CF) personnel.

DRDC Toronto's new Applied Research Project (ARP) entitled "Preliminary Development of Integrated Physical Ergonomics Modeling Tools to enhance Warfighter Effectiveness" is seeking to identify stakeholder needs for integrated physical modeling tools (users and workspace), and to survey the state-of-the-art and acquire the most suitable, affordable, available tools for measuring and modeling the physical aspects of Canadian warfighters. The ARP will also develop and implement plans to improve tools, integrate with other HSI (Human System Integration) tools, and populate these tools with current data. In addition, critical tasks and workspaces that are pertinent to CF acquisition projects in Horizon 2 will be modeled.

The purpose of this report is to present methods and results from the front-end analysis that was conducted on stakeholder needs, and to present the detailed survey of state-of-the-art tools.

1.1 Organization of this Report:

This report is organized into the following sections:

Section 2. Aims: describes the project aims.

Section 3. Method: summarizes the approach taken.

Section 4: Project Needs: describes the needs for physical ergonomic tools among the projects/programs and departments interviewed.

Section 5: State-of-the-Art Review: summarizes the biomechanical tools by function and tool type.

Section 6: Mapping Project Needs to Tools: provides recommendations from the State-of-the-Art review to satisfy the highest priority requirements from the Needs analysis.

Annex A: Detailed Tool Information: provides additional technical and review information in this annex for all tools investigated in this review.

2. Aims

The following were aims of the project:

- Identify stakeholder needs for integrated physical modeling tools (users and workspace);
- Survey and assemble product details for state-of-the-art tools for measuring and modeling the physical aspects of Canadian warfighters;
- Prioritize tools against the identified stakeholder needs.

3. Methods

For the stakeholder needs analysis, DND and industry stakeholders were consulted for requirements of current warfighter system and transport vehicle projects. Their requirements were made known for integrated physical ergonomics data capture, analysis and modeling tools. Consultation included DRDC scientists, project and matrix staff from DGLEPM, DLR, and representatives from air and maritime platform acquisition projects.

The state-of-the-art review of current physical ergonomics tools was conducted by reviewing product and scientific literature. Tool developers and manufacturers were contacted for technical details and pricing information. Tools were categorized by function and tool groups within each function. Product details were compiled and a summary description of each tools and their pros and cons was derived. As far as possible, we have tried to be comprehensive and representative in the listing of candidate technologies and products.

4. Project Needs

The following projects/programs and departments were interviewed to determine their on-going and projected needs for physical ergonomic tools and resources.

Land	Sea	Air
• TAPV • CCV • CTS • DLR-3 • MSVS • DLR-5 • ISSP • DRDC Blast Survivability • DRDC PPE • DRDC SARP2	• NICE • DMRS 7: Frigate Replacement Program	• DTAES-6 • CH-146 Griffon

4.1 Land

4.1.1 Tactical Armoured Patrol Vehicle (TAPV)

Project Description: As part of the Land Combat Vehicle Systems program, the TAPV project will deliver a wheeled combat vehicle with a high degree of tactical mobility and a very high degree of crew survivability. As a minimum, the TAPV will fulfil the following roles: reconnaissance and surveillance, security, command and control, cargo, and armoured personnel carrier. The project is currently at the request for proposal stage.

Physical Ergonomic Tool Needs:

a) *Anthropometry:* TAPV noted that they need updated anthropometric data for all relevant Land Force MOSIDs. They perceive the current LF97 survey to be outdated.

b) *Clothed Anthropometry:* There is a significant requirement for representing the range of anthropometric sizing in a fully, operationally clothed configuration to more accurately reflect volumetric requirements and clearances. Current semi-nude anthropometry significantly under-estimates both crew and passenger compartment requirements for fit and accommodation.

c) *Virtual Modeling:* TAPV noted that, while it is important to have up-to-date anthropometric data, they also need a means to employ the data in their vehicle models. They felt that this capability would be particularly valuable for undertaking early assessments of mid-life upgrades. Dynamic virtual models of common tasks and activities could be run in a test battery of alternative mid-life upgrade designs across a range of clothed anthropometric sizes.

d) *Forces:* Capturing information about typical forces and torques required in a given operational or maintenance task could be useful in assessing the suitability of alternative designs.

e) *Performance Measures:* A battery of performance measures would be useful for evaluating the impact of design modifications, vehicle designs, and mid-life upgrades. Tasks could include emergency egress, maintenance tasks, reach requirements within set times, and even activities like the time required to fasten seat belts.

f) *Other:* TAPV suggested that a repository of HSI standards (web based) would be useful for both industry and PMOs for undertaking preliminary decisions.

4.1.2 Close Combat Vehicle (CCV)

Project Description: The CCV project will deliver an extremely well protected armoured vehicle with very high tactical mobility, able to transport an infantry section in close contact, while operating in support of CF tanks. The CCV is envisaged as a medium armoured capability (25-45 tonnes) that will bridge the gap between the current light (5-20 tonnes) and heavy armoured (45 tonnes +) vehicle fleets. Specifically, the CCV will increase force/crew survivability, providing troops with the enhanced protection and mobility of a medium armoured vehicle, allowing them to effectively operate in intimate support of CF tanks in close combat with enemy forces. The project is currently at the request-for-proposal stage.

Physical Ergonomic Tool Needs:

a) *Anthropometry:* MOTS programs are less interested in critical dimensions and more interested in best fit accommodation. Representative, accurate anthropometric data will be required to assess the percentage accommodation provided by each bid contender for crew stations, hatches, and passenger areas.

b) *Clothed Anthropometry:* Different vehicle programs are making different assumptions and using different data sets for clothed anthropometry. The CCV program needs a common, validated CF standard data set for clothed soldiers.

c) *Virtual Modeling:* The CCV program has completed workflow and task analyses for each crew station position in the CCV vehicle. Virtual modeling could be used to run task flow scripts to assess crew station accommodation, safety issues (e.g. emergency egress, injured crewman extraction), and team crewing activities.

d) *Crew station Modeling:* The capability to scan an actual crew station and then represent it accurately in a virtual 3D space would be a valuable asset to support the virtual modeling activities above.

4.1.3 Clothe the Soldier (CTS)

Project Description: The goal of the CTS project is to clothe and equip the Land Force with individual environmental and battlefield protective clothing and equipment to address deficiencies with in-service items. Items include handwear, footwear, and headwear systems, environmental clothing, ballistic protective equipment, and load carriage items.

Physical Ergonomic Tool Needs:

a) *Anthropometry:* Accurate, up-to-date anthropometric data is essential to the CTS project. Decisions about sizing ranges and tariffs will benefit significantly from such a resource and result in greatly reduced lifecycle costs. Similarly, the consolidated clothing project believes that it would benefit by having detailed anthropometry data collected at the same time as BOSS data so that they could continue to validate and improve the BOSS system.

b) *Performance Testing:* CTS supports the use of performance testing through soldier-centric field trials to validate design concepts and verify that bid designs meet User requirements.

4.1.4 DLR-3: Light Armoured Vehicle (LAV) Upgrade

Project Description: The LAV upgrade project, and other similar vehicle upgrade and life extension efforts, will replace and enhance capabilities of the vehicle system in the areas of mobility, survivability, habitability, lethality, and C4I.

Physical Ergonomic Tool Needs:

a) *Anthropometry:* DLR-3 requires precise, representative anthropometric data for all Land Force personnel that may operate or be transported in an Armoured Fighting Vehicle (AFV). Canada undertakes COTS acquisitions and then needs to adopt fit accommodation strategies to ensure we can adequately fit our soldier population. To do this effectively requires an accurate, comprehensive database of soldier dimensions.

b) *Clothed Anthropometry:* Key to soldier fit accommodation in AFVs is knowledge about the volumetric dimensions of soldiers in all their various combat load order conditions. One possible accommodation strategy is soldier sizing limits to ensure certain sizes of soldiers are not placed in an unsafe condition when there are no design accommodation strategies available. The driver for the Leopard tank is a good example of having to limit the stature of drivers to ensure safe accommodation.

c) *Virtual Modeling:* DLR-3 considered virtual modeling an effective tool for assessing soldier task performance and in-vehicle fitting issues when investigating early accommodation concepts or when considering new design upgrades and new equipment installations.

d) *Crewstation Modeling:* The capability to rapidly capture the 3D layout of vehicle spaces for use in virtual modeling applications was seen to be a valuable capability.

e) *Performance Measures:* A battery of performance measures for AFVs would be useful for evaluating the impact of design modifications, vehicle designs, and mid-life upgrades. Tasks could include emergency egress, maintenance tasks, reach requirements within set times, and even activities like the time required to fasten seat belts.

f) *Other:* More knowledge about the implications of different soldier accommodation strategies in a vehicle would be useful guidance to Commanders in the field. This knowledge would include soldier size implications for performance and safety,

density of soldiers and equipment for task performance and safe emergency practices, etc.

4.1.5 Medium Support Vehicle System (MSVS)

Project Description: The aim of the Medium Support Vehicle System (MSVS) project is to procure new medium-sized logistics trucks for the Canadian Forces. This new fleet will be used by the Regular Forces and the Reserves in a wide range of roles - from support during domestic emergencies, to deployed operations. This platform will include variants for unit logistics, mobile support facilities (kitchens, workshops, medical facilities), and provide tactical movement support.

Physical Ergonomic Tool Needs:

a) *Anthropometry:* Representative, accurate anthropometric data will be required to assess the percentage accommodation provided by each bid contender for cab design, access/egress, passenger spaces, and maintenance activities.

b) *Clothed Anthropometry:* The MSVS program would benefit from a common, validated CF standard dataset for clothed soldiers for assessing the suitability of the MSVS in all its variants.

c) *Cab Modeling:* The capability to scan actual bid crew cabs and represent them accurately in a virtual 3D space would be a useful capability for assessing bid contenders.

4.1.6 DLR 5: Soldier Systems

Program Description: DLR 5 maintains a continuous program of soldier system enhancement and integration in the areas of survivability, mobility, lethality, sustainability, and C4I. Future programs include the Close Combat Modular Fighting Rig to develop a new load carriage vest system (2011-2016), Soldier Survivability Systems for sleeping systems and tent shelters (ongoing), Future Combat Uniform (2014-2015), Next Generation Soldier Protection for head-to-toe layered protection (2014-2015), Thermal Weapon Sight (ongoing), Small Arms Replacement Program 2 to develop and replace all small unit weapons (2012-2020), Integrated Soldier System Platform (2011-), Enhanced ISSP (2024), and finally the Soldier System 2030 Program that will seek to fully integrate all soldier system components (starting in 2023).

Physical Ergonomic Tool Needs:

Tool needs below reflect the more programmatic-level viewpoint of DLR.

a) *Anthropometry:* An up-to-date, comprehensive anthropometric survey of the current Land Force is required to replace the outdated LF97 survey. Given the wide range of equipment, clothing, and vehicle being considered and reviewed in DLR, the dataset should be as large as practicable.

b) *Clothed Anthropometry:* DLR requires more insight and awareness of the volumetric results of different operational clothing and equipment configurations to assess

design and acquisition decisions, and more accurately reflect volumetric requirements and clearances to programs that seek to integrate soldiers. Volumetric models should be developed for the typical range of temperate, winter, and arctic load orders.

c) *Performance Measures:* DLR would like to have a test battery of tools to help assess the impact of clothing and equipment design concepts on soldier mobility and combat task performance. Such a capability would be useful in helping to derive requirements for item acquisition and for evaluating subsequent bid submissions to meet those requirements.

d) *Other:* Other test rigs and assessment methods would also be useful to evaluate critical design criteria in select equipment and load carriage. An example is the Queen's load carriage rig which provides objective measures of load carriage effects prior to soldier testing.

4.1.7 Integrated Soldier System Project

Project Description: The Integrated Soldier System Project will provide the soldier with an integrated suite of equipment that includes weapon accessories, electronic devices, sensors, individual equipment and operational clothing. This soldier system will significantly increase soldier performance, as soldiers and low-level command centres will seamlessly share data and voice communications through a network. This capability will facilitate effective and timely interaction. As a result, soldiers will have more comprehensive situational awareness, real-time tactical information and greater synchronization of activity. The project is planning to release a request for proposal stage in Fall 2011.

Physical Ergonomic Tool Needs:

a) *Anthropometry:* Effective integration of the ISSP system will require an accurate, representative dataset for the Land Force. A key focus of ISSP will be the torso surface area available for mounting the system components.

b) *Clothed Anthropometry:* ISSP has particular interest in mapping the torso vest area for usable mounting space for ISSP components. Mounting solutions may need to vary depending on torso size and shape.

c) *Virtual Modeling:* Anthropometrically accurate virtual soldier models would improve the quality and efficiency of designing and evaluating alternative ISSP component layouts. Ideally, virtual models would be capable of performing a battery of combat-relevant activities and movements.

d) *Motion Capture:* Motion capture capabilities would enable the development of the movement scripts necessary to model the virtual soldier activities and movements.

4.1.8 DRDC-Valcartier: Vehicle Occupant Blast Survivability

Program Description: This research program is aimed at assessing blast effects of vehicle occupants in various vehicle types, sizes, and configurations for different soldier locations, postures, clothing, and armour states.

Physical Ergonomic Tool Needs:

a) *Anthropometry:* Accurate anthropometric data would improve the quality and validity of the blast effects models and help identify the specific proportions of the Canadian Forces that are most vulnerable.

b) *Clothed Anthropometry:* Actual clothed soldier dimensions would contribute to improving the accuracy of blast survivability models. Current models lack specific details of the position and location of Personal Protective Equipment (PPE) in seated postures and how this varies as a function of soldier size.

c) *Virtual Modeling:* 3D CAD models of these anthropometrically representative, clothed soldiers would be useful for use in existing blast model simulations.

d) *Motion Capture:* The capability to capture task-specific movements in the vehicle spaces, when wearing PPE and constrained by the presence of other soldiers and equipment in the spaces, would provide valuable insights into clearances and co-locations of personnel and equipment relative to vehicle surfaces.

e) *Other:* Having more information about the range of soldier sizes and the positioning of PPE relative to the threats would help improve the accuracy and validity of lethality/incapacitation models.

4.1.9 DRDC-Valcartier: Personal Protection Systems

Program Description: This research program is aimed at designing and evaluating the survivability and usability of protective headwear and body armour design concepts and material solutions to protect the individual soldier.

Physical Ergonomic Tool Needs:

a) *Anthropometry:* Accurate anthropometric data would be extremely valuable in the design and trade-off analyses that are commonly undertaken in PPE research. Similarly, accurate 3D head scans would be very beneficial for headwear protection design efforts and support shape optimization efforts.

b) *Clothed Anthropometry:* Clothed anthropometry data would be useful for mapping integration options with existing clothing and equipment ensembles throughout the range of soldier sizes, as available 'real estate' can vary significantly over that sizing range.

c) *Virtual Modeling:* Virtual models of soldiers would provide a very useful design tool if the software tool could vary the dimensions of a soldier in each designed size range to facilitate analyses of accommodation, clash, and integration.

d) *Motion Capture:* Mobility assessments of combat tasks and activities while wearing prototype PPE ensembles and equipment would benefit from objective motion

capture systems that can provide detailed biomechanical information on joint angles and ranges of motion, torques, etc.

e) *Data Acquisition:* Various data acquisition tools would be beneficial for evaluating the performance and effectiveness of different designs. Tools that measure range of motion, muscular effort, outcome force, and torque would be useful for PPE assessments.

4.1.10 DRDC-Valcartier: Small Arms Replacement Program 2

Program Description: This research and development program will develop Statements of Requirement for small arms weapons through research, material testing, advanced fire control systems, precision effects technologies, and soldier usability, to support the CF SARP 2 capital project.

Physical Ergonomic Tool Needs:

a) *Anthropometry:* Detailed anthropometry for the head, arms, hands, shoulder carriage, and upper torso would be extremely useful for designing physical interfaces for weapon systems and deriving accommodation ranges in the designs to suit the CF population.

b) *Clothed Anthropometry:* Torso clothing and equipment (e.g. combat load and PPE) introduce significant challenges to integration for a highly precise positioning task where repeatability is important to weapon aiming and target engagement effectiveness. Weapon designs that integrate effectively with these clothing and equipment ensembles, across the range of soldier sizing, would benefit from detailed clothed anthropometry data.

c) *Virtual Modeling:* Virtual models of clothed soldiers would support the weapon design effort in general. If the characteristics of weapons physics could also be represented in the virtual models, with associated human model reactions to those physical effects then this method could offer significant benefits for the development of meaningful requirements.

d) *Motion Capture:* The assessment of weapon concepts, prototypes, and functional models would benefit from objective motion capture systems that could capture key weapons handling tasks and activities, and the biomechanical responses of the body to them.

e) *Data Acquisition:* Various data acquisition tools would be beneficial for evaluating the performance and effectiveness of different designs. Tools that measure range of motion, muscular effort, outcome force, and torque would be useful for weapons assessments.

4.2 Sea:

4.2.1 Naval Improved Clothing and Equipment (NICE)

Project Description: The goal of NICE is to provide state-of-the-art operational clothing and equipment to Naval personnel to enhance functionality, survivability, interoperability and combined operations anywhere in the world. Items include handwear, footwear, and headwear systems, environmental and rainwear clothing, armour eyewear and vests, and combat dress.

Physical Ergonomic Tool Needs:

a) *Anthropometry:* Accurate, up-to-date anthropometric data is essential to the NICE project. Decisions about sizing ranges and tariffs will benefit significantly from such a resource. Priority would go to floatation system sizing and protective clothing and equipment for naval boarding parties.

4.2.2 DMRS 7: Frigate/Destroyer Replacement Program

Program Description: This program will modernize the 12 HALIFAX Class multi-role patrol frigates are considered the primary vessel of the Canadian Navy. Over time the operational profile for the frigates have changed and must address current and evolving threat systems that are faster, stealthier, more maneuverable and are moving from open-ocean areas to the littoral environment. The modernization will include a new command and control system, new radar capability, a new electronic warfare system and upgraded communications and missiles. Separate refit and stand-alone projects will include installation of new mechanical systems and modifications to accommodate the new Cyclone helicopters and a new military satellite communications system.

Physical Ergonomic Tool Needs:

a) *Anthropometry:* Anthropometry data is important for setting and evaluating requirements for habitability standards and crew station/maintenance space design. DMRS would also benefit from support in defining HSI criteria, measurement methods, and compliance determination.

   Up-to-date anthropometry data is required for setting requirements and tariffs for all clothing and equipment acquisitions. Key protective equipment items (e.g. firefighting protective equipment) would benefit from more extensive and precise anthropometric information to support acquisition.

b) *Clothed Anthropometry:* Crew spaces, hatches, maintenance space, etc. are all limited on board ship. A clothed anthropometry dataset would be beneficial in determining requirements for accessibility and clearance in all ships spaces.

c) *Motion Capture:* Given the confined spaces typical for ship crew stations and maintenance spaces, it would be useful to be able to capture the motions and actions required is mission-critical tasks to support design optimization in virtual modeling tools.

d) *Virtual Modeling:* Anthropometrically accurate virtual models of clothed sailors would be beneficial for assessing the suitability of crew stations and spaces during acquisition, refits, and upgrades.

e) *Forces:* Information about the typical forces and torques required in a given operational or maintenance task, and the musculo-skeletal demands on crew members, would be useful in assessing the suitability of contender equipment and design modifications.

f) *Performance Measures:* Movement time through a ship is critical for damage control, evacuation, and fighting the ship. Simulation tools for modeling movement times and the flow of crew members during various scenarios would be useful for optimizing ladder and hatch locations.

4.3 Air:

4.3.1 DTAES 6

Program Description: The Directorate of Technical Airworthiness and Engineering Support (DTAES) ensures that the Canadian military fleets and foreign military aircraft within Canada achieve and maintain an adequate level of safety and effectiveness from a technical perspective and comply with the requirements of the DND/CF Airworthiness Program. DTAES 6 provide Engineering Services in the domains of Aircraft Electrical Systems, Electromagnetic Environmental Effect (E3), Human Factor Engineering/Human System Integration, Avionics and related Software.

Physical Ergonomic Tool Needs:

a) *Anthropometry:* DTAES-6 indicated a strong need for anthropometric data for fixed wing and Griffon pilots, cabin crew, maintainers, and ground crew. Accurate, up-to-date anthropometric information is key to ensuring effective, on-going accommodation of Air Force personnel.

b) *Clothed Anthropometry:* Clothed anthropometry is important for assessing the bulk implication clothing and equipment ensembles but compressed clothing measurement methods may not reflect the critical issue of snagging hazards. Ideally, clothed anthropometry assessments would include compressed and uncompressed measures. Clothing ensemble assessments must include crew station and air craft working environments, as well as aircrew escape-and-evade ensembles.

c) *Virtual Modeling:* Virtual modeling offers a number of advantages for early assessment of airframes, crewstations, maintenance spaces, etc. for the purposes of evaluating the suitability of new designs, upgrades, and modifications. Using virtual models, these assessments would inform accommodation issues for a complete range of anthropometric dimensions in the range of relevant clothing ensembles.

d) *Motion Capture:* Many crewstation activities involve predictable movement scripts to perform a battery of operational and emergency activities and tasks in crew position. Having a library of these motion scripts would be very useful for running clothed avatars in virtual modeling assessments.

e) *Crewstation Modeling:* The capability to rapidly capture the 3D layout of crew spaces for use in virtual modeling applications was seen to be a valuable capability. Given the schedule of future design modifications, DTAES-6 recommended focusing on capturing pilot/flight crew stations over maintenance spaces. The CH-146 was seen to be a good place to start since this aircraft is slated to upgrade to new armoured seats, accommodate new Personal Protective Ensembles for pilots, and will received design changes to the internal configuration of the crew spaces.

f) *Performance Measures:* A battery of performance measures for crewstations in select aircraft would be useful for evaluating the impact of design modifications, vehicle designs, and mid-life upgrades. Tasks could include emergency egress, maintenance tasks, reach requirements within set times, and even activities like the time required to harness safely into a seat.

g) *Other:* One of the key points raised by DTAES-6 was the capability to maintain the currency of critical anthropometric data and crewstation models.

4.3.2 CH-146 Griffon Program

Program Description: The CH-146 Griffon is a Utility Transport Tactical Helicopter (UTTH) used primarily for search and rescue (SAR) missions, tactical transport and humanitarian relief operations. The Griffon features GPS satellite navigation and Doppler radar systems. It is equipped with a hoist that enables it to extract people and cargo from almost any terrain. The Griffon can be equipped with a Forward-Looking Infrared (FLIR) system and a powerful searchlight, helping it to navigate and search in low-visibility conditions. The aircraft can carry up to 13 people (two pilots, a flight engineer and 10 passengers). Human System Integration opportunities in the program relate to upgrades and modifications to the existing airframe, design integration, and equipment acquisition.

Physical Ergonomic Tool Needs:

a) *Anthropometry:* Accurate, up-to-date anthropometric information is needed to support future modifications and upgrades on the existing airframe and any acquisition issues in new airframes. Upcoming upgrades will require a thorough seat change analysis for the door gunner position.

b) *Clothed Anthropometry:* Crew and passenger accommodation, and access/egress, issues in crew station design and passenger compartment upgrades and installations can benefit from comprehensive, up-to-date clothed anthropometry data.

c) *Virtual Modeling:* Early assessments of crew station and passenger compartment designs can be cost-effectively assessed using virtual human models with 3D models of the Griffon systems.

d) *Motion Capture:* Motion capture of typical task sequences in each crew station, and access/egress movements in the passenger and crew station compartments, would be useful in assessing Griffon modifications. As well, there are concerns with back and neck stress/injury due to postural demands associated with viewing the FLIR screen interface and other demanding postures during flight and hover manoeuvres. Tools for tracking postural changes and states would be useful in designing to mitigate postural problems.

e) *Forces:* Griffon seat design assessments include questions of vibration damping and postural stability. Measurement tools to support these analyses would be useful.

f) *Crew station Modeling:* The capability to scan actual cockpit layouts and candidate equipment and then represent them accurately in a virtual 3D space would be useful for the virtual modeling activities above.

4.4 Priority of Needs:

While the projects/programs and departments interviewed for this needs analysis only represent a sub-set of potential "clients" for physical ergonomic tools and a snap-shot in time, we can derive an indication of relative priority to help guide the selection and development of such tools. Figure 1 below summarizes the proportion of interviewees that indicated a need for a particular tool.

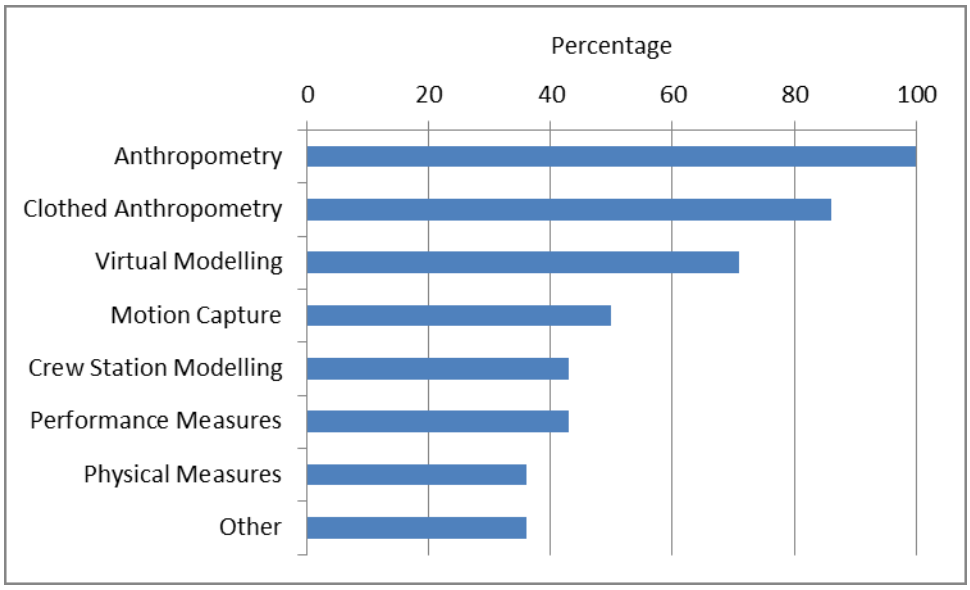


Figure 1: Priority of Physical Ergonomic Tools

Both semi-nude and clothed anthropometry tools were rated very highly by almost all interviewees. Tools that contribute to the development of virtual models and the use of virtual service personnel engaged in both static and dynamic activities were also judged to provide considerable benefit to the research, design, and development of clothing, equipment, crew spaces, and vehicles (i.e. virtual modeling, motion capture, and crew station modeling). Tools that could be used to quantify performance and physical attributes were seen to be useful for some.

5. State-of-the-Art Review

The state-of-the-art review of current physical ergonomics tools was categorized by Function and then Tool Group. A summary of the review is presented below and the detailed review is provided in Annex A. Note that the numbering system in the Annex matches the numbering in this section.

5.1 Function: Measurement – Human

The function of human measurement included accelerometry, anthropometry (traditional, photogrammetry, 3D scanning, and clothed), data acquisition (force, torque, grip force, goniometers/torsiometers), EMG, force plates, motion capture systems, pressure mapping, range of motion, and soldier performance measures.

5.1.1 Accelerometry

Tool	Summary Description	Pros	Cons
NexGen Series 3 Accelerometer	Tri-axial Accelerometers that provide three outputs, simultaneously measuring acceleration along the X-, Y- and Z-axes. The transducers can be used on any part of the body or attached to external equipment. $2000 to $2400 per accelerometer, plus $6500 for DataLOG	Extremely small and lightweight, very high range for dynamic and impact testing applications. Wireless DataLOG.	Complex analysis of data, calibration not easy, instrument drift possibilities relatively expensive
Noraxon 3D Accelerometer	Compact and lightweight acceleration sensor especially designed for use with human and animal surfaces and body segments. Due to its size and mass, it is easy to attach and provides accurate data. It can measure impact forces up to 6G (Standard) or up to 16G (optional version). Designed for use with Noraxon physiological data collection system. $1000 plus $9500 for data collection system and software	Selectable DC filter, very small and lightweight, easily interacts with Noraxon data collection units, designed for human attachment	Restrictive cable length, requires Noraxon data collection system, relatively expensive

BioPac TSD109 Accelerometer	Tri-axial Accelerometers that provide three outputs, simultaneously measuring acceleration along the X-, Y- and Z-axes. The transducers can be used on any part of the body or attached to external equipment. $7100 for accelerometer, wireless receiving unit, software, and accessories.	High acceleration (50G) and low acceleration (5G) sensors available, easy calibration, high frequency response, long cable, designed for human attachment	Larger than similar sensors, relatively expensive
Onset: Hobo Pendant Accelerometer	The HOBO Pendant G Acceleration Data Logger is a waterproof, three (3) channel logger with 8-bit resolution that can record up to approximately 21,800 combined x-, y-, and z-axis acceleration readings or internal logger events. The pendant logger uses a coupler and optical base station with USB interface for launching and data readout by a computer. $75 per pendant, $150 for kit with software	Relatively low cost, wireless, simple operation	Not designed for human attachment; requires mounting system. Low dependability – back-up modules are recommended. Time-collection span limited by sampling rate.

5.1.2 Anthropometry: Traditional

Tool	Summary Description	Pros	Cons
Centurion Measuring Kit	1 Campbell 20" Sliding Caliper, 1 Campbell 10" bone caliper, 1 Segmometer 4, 1 Head Square with tape, 2 Slim Guide Skinfold Calipers, 2 Steel Anthropmetric Tapes, 1 Anthropometric Devices Fundamentals CD, 1 Cordura carry case. $1530	Relatively inexpensive	Unknown construction and materials, durability unknown, not large enough for height measurement
GPM (distributed by Seritex Inc) Large Instrument	Anthropometer, curved crossbars, sliding calliper, spreading calliper with rounded or pointed end,	The gold-standard kit, robust, durable,	Relatively expensive

Anthropometry Kit	measuring tape. $7243	large enough to measure height	
Mentone Educational Centre Anthropometer Measuring Set	Anthropometer, Rod measures, Straight rules, Curved rules, Tasterzirker callipers, Gleitzirkel Martin's Thickness Gauge, Stainless Steel rule, Stainless steel tape measure, Finger Sterilizing Case, Carrying Case. $2970	Cheaper than Seritex GPM Kit, durable construction, large enough to measure height	No base plate for anthropo-meter

5.1.3 Anthropometry: 2D Photogrammetry

Tool	Summary Description	Pros	Cons
Body Scanning System 21st Century (BoSS XXI)	Takes 3 simultaneous high-res photos (Front, Side, Top), calculates 77 different body measures, computes proper garment sizes, creates and maintains a database of body dimensions & garment sizes. $54,000 to $59,000	Simple, cost-effective, good for clothing sizing	2D (not 3D), only 14 metrics are directly measured, remainder are inferred

5.1.4 Anthropometry: 3D Scanning

Tool	Summary Description	Pros	Cons
Human Solutions: Vitus Smart	3D Body Scanner with high degree of accuracy, 4-column scanner, especially suited to research applications. $230,000	Large scan-space to facilitate non-typical postures and garments, high volume scanning, very accurate, high resolution, software allows for multiple postures and semi-automatic measurements with landmarks. Meant for research (including defence research). Software gives	Relatively expensive, long scan time (12 sec for whole body - too long for critical research)

		140 anthro measures automatically, and custom measures can be added.	
[TC]2 NX-16	White-light scanning technology, small size, safe, private, relatively inexpensive. $37,500	Relatively inexpensive, automatic avatar generation.	Small scan space, lower resolution, software only allows for one posture, cuts of bottom of legs, meant for apparel industry
[TC]2 LC-16	White-light scanning technology, small size, safe, private, cheap (cheaper than NX-16) $27,500	Relatively inexpensive.	Small scan space, lower resolution, software only allows for one posture, cuts of bottom of legs, meant for apparel industry
3dMD	3dMD's imaging systems are the most widely used ultra-fast, high-precision 3D surface imaging devices. The 3dMDbody System is a highly flexible configuration that allows for a large number of variations in camera positioning and lenses. Systems can be customized as head scan, torso scan, full body as well as 4D systems that capture dynamic motion (60frames per second). $244,000	Freezes human motion (whole body in 1.5 ms) so it is very precise (e.g. for fitting eyewear or gas masks). Large scan-space to facilitate non-typical postures and garments, high volume scanning, very accurate, high resolution, software allows for multiple postures and landmarking. Can be custom programmed for automatic measures. Meant for research (including defence research).	Relatively expensive, software does not give automatic anthro measures
Cyberware	Cyberware's Head & Face Color 3D Scanner is designed to offer maximum	Four scanheads are at optimum angles to capture complex contours (especially	Relatively expensive, long scan time

	coverage scanning of the human head and face. The system is designed for applications that will benefit from increased scan coverage of the top of the head and under cut areas of the chin. Cyberware's Whole Body Color 3D Scanner takes hundreds of thousands of measurements of the human body in 17 seconds. Four scanheads collect high-speed 3D measurements every 2 mm from head to toe to create an accurate 3D data set. Head and Face: $63,000 to 77,000 Whole Body: $200,000 to $240,000	for faces), improved coverage greatly reduces post production editing, software can be set up for automatic anthro measures.	(not as precise as 3dMD)

5.1.5 Anthropometry: Clothed

Tool	Summary Description	Pros	Cons
Clothed Anthropometry using traditional and 3D Scanning	Traditional anthropometry can be used to ascertain girth, width, and depth measurements; 3D scanning can be used to ascertain bulk and spatial volumes.	Provides the impact of clothing on design of workspaces	Difficult to accurately and repeatedly measure

5.1.6 Data Acquisition: Force

Tool	Summary Description	Pros	Cons
Multi-Component Force Sensor	Multi-function force transducer to measure real-time forces and moments in and about the three principal axes (x, y, z). Applications range from clinical to laboratory to material testing. Very accurate measurements with low error and compact design. Specifications vary slightly with manufacturer. $7000	Robust set of low-error, real-time analog signals. Multitude of uses, mounting options, and attachment possibilities.	More expensive than less-robust force transducer types. Require use of an auxiliary amplifier and third-party collection software.
Tri-Axial Force Sensor	Force transducer to measure real-time forces in three principal directions (x, y, z). Ideal for unidirectional and off-axis force application in occupation, clinical or laboratory settings. Range in size from small (3") for clinical applications to large plates (>6") for materials testing. $3600	Accurate, real-time force recording. Mounting plates for surface-mounting and handle/tool mounting. Less expensive than multi-component.	Cannot record real-time applied moment/torque values. Require use of an auxiliary amplifier and third-party collection software.
Uni-Axial Force Sensor	Stand-alone device to measure linear force (tension/compression). Typically only display force level, rather than generate real-time recordings. Very compact, battery-powered, and require no external hardware. $556	Easy to use, simple display, multiple accessory attachments. Battery powered, requires no external hardware. Low price.	Limited to uni-directional force measurement, and does not account for off-axis force contributions. Cannot record time-series data.

5.1.7 Data Acquisition: Torque

Tool	Summary Description	Pros	Cons
Kistler	Kistler 9275: High-capacity, cylindrical real-time torque measurement device. Allows accurate, uni-directional torque recording via mountable plate surfaces. $5300	Extremely high torque capacity. Recordable, real-time analog signal. Versatile mounting surfaces.	External amplifier and recording system required. Higher levels of signal hysteresis and non-linearity.
Futek	Futek TFF600: Cylindrical real-time torque measurement device. Allows accurate, uni-directional torque recording via mountable plate surfaces. $1250	Highly sensitive, allowing accurate measurement even at very low torque levels. Recordable, real-time analog signal. Versatile mounting surfaces. Lower cost.	External amplifier and recording system required. Lower torque capacity than other, similar products.
Chatillon	Chatillon DFS-R-ND: Torque measurement accessory for Chatillon DFS-R-NS Series force measurement devices. Chuck type adapter for insertion and measurement of torque about a sample. $1210	Force measurement available as well as torque. Measures applied load rather than reactive load (better for dynamic tool tasks). Lower cost.	Much lower torque application capacity. Less versatile chuck-insertion interface.

5.1.8 Data Acquisition: Grip Force

Tool	Summary Description	Pros	Cons
Analog Hand Grip Dynamometer	Grip force measurement device with analog dial gauge display. Accurately measure whole hand	Adjustable grip spans for various hand sizes. No external equipment required. Relatively low price. Can view	Less accurate than digital models. Requires visual increment differentiation.

	grip force and allows user to view variations in grip force over time. Ideal for evaluation of strength gain/loss due to training/pathology or occupational task requirement evaluation. $300	variations in force during sustained gripping tasks.	Mechanical device; cannot record measurements or define measurement interval.
Digital Hand Grip Dynamometer	Grip force measurement device with digital LCD dial gauge display. Accurately measure maximum whole hand grip force. Ideal for evaluation of strength gain/loss due to training/pathology or occupational task requirement evaluation. $350	Easy-to-read digital display. No external equipment required. Adjustable grip spans for various hand sizes. Relatively low price ($350). Accurate recording of maximum grip force during measurement interval. Some models allow calculation of average and standard deviation of measurement interval.	Can only record maximum achieved grip, cannot see strength variations in a measurement interval if below maximum grip force.
Integrated Hand Grip Dynamometer	External grip force measurement attachment for Noraxon EMG systems. Allows measurement of hand grip force, pinch grip force and provides real-time biofeedback. Designed for use with Noraxon physiological data collection system. $600 to $3000 (depending on force range) plus $9500 for data collection system and software	Multiple measurement types possible (hand grip force, pinch grip force, biofeedback). Time-varying recordable signal that allows for post-processing. Extremely accurate signal. No calibration or installation required.	Requires Noraxon physiological data collection system. Most expensive. Non-adjustable grip span.

5.1.9 Data Acquisition: Goniometers / Torsiometers

Tool	Summary Description	Pros	Cons
Single-Axis Goniometers	Flexible sensor for measurement of joint angle in a single plane of motion. $680	Easy-to-use, direct and easily interpreted measurement, no line-of-sight dependence	Only a single axis of motion, difficult to ensure angle accuracy
Twin-Axis Goniometers	Flexible sensor for measurement of rotation of a joint angle in a single axis (eg. pronation/supination). $810	Reasonable joint angle repeatability, direct and easily interpreted measurement, no line-of-sight dependence	Local data only, device may alter natural joint movements, difficult to ensure angle accuracy
Single-Axis Torsiometers	Flexible sensor for measurement of joint angle in two simultaneously planes of motion. $680	Easy-to-use, direct and easily interpreted measurement, no line-of-sight dependence	Soft tissue motion artifact, local data only, requires mathematical transformation for differentiation

5.1.10 EMG

Tool	Summary Description	Pros	Cons
Motion Lab Systems	Fully customizable backpack EMG system. System packages are available consisting of all required components or could be tailored to user needs. System highlight is ability to quickly be modified into a telemetric system. $13,000 to $40,000 depending on number of	Telemetric plug-in add-on available, fully customizable from 6 to 18 input channels, condensed single backpack unit	Devoted EMG channels cannot be used for auxiliary devices, low input impedance

	channels and capabilities		
Delsys	Stand-alone desktop EMG system that includes all required components. Systems feature reliable components and parallel bar skin sensors rather than standard gelled EMG electrodes. $6,500 to $30,000 depending on number of channels and wireless options	Diverse number of inputs available and can be used for auxiliary devices, integrated interference and saturation checks, parallel bar sensors require no skin preparation	Smaller EMG bandwidth than other systems
Noraxon	Expandable, telemetric EMG system with up to 32 analog input channels for wireless transmission to desktop or notebook recording stations. $19,000 to $29,000 depending on number of channels	Wireless, 32 channel inputs exceed other systems, complete line of plug-in sensors are compatible	Hard-set sampling rates, possibility of signal latency, higher cost for telemetered systems
TMS International	Multi-channel ambulatory and stationary system for physiological research. Versatile analog inputs allow for measurement of various physiological signals including EMG, ECG, temperature, kinematics and kinetics. $11,000 to 17,000 depending on number of channels	Versatile inputs channels to accept various physiological measurements, active shielding provides optimal signal quality, ability to be hard wired or battery operated with Bluetooth telemetry	Systems components sold separately, no hardware filtering, limited bandwidth when telemetered, data is recorded within device, limiting real-time abilities

5.1.11 Force Plates

Tool	Summary Description	Pros	Cons
AMTI	Six-channel force platform ideal for gait, balance and posture studies $10,000	Very high force capacity ideal for dynamic athletic tasks as well as gait and balance studies, light weight ideal for mobile force platform mounting solutions, high resonant frequency	No cross-talk correction, external mounting plate, amplifier and collection software required
Bertec	Six-channel force platform ideal for gait, balance and posture studies $10,000	Force capacity sufficient for static or dynamic gait and balance tasks, built-in 16-bit digital amplifier and signal conditioning unit, internal cross-talk correction	External mounting plate, amplifier and collection software required
Kistler	Three-channel force platform ideal for material testing, and machine foundation evaluation $22,000 to $39,000	Extremely high force capacity and frequency response for machine or materials testing	Only three output channels, moments not measured directly, not intended for use in human evaluation studies, most expensive

5.1.12 Motion Capture Systems

Tool	Summary Description	Pros	Cons
Passive Optical e.g. Vicon	Passive optical motion tracking systems use retroreflective markers to reflect back infrared light generated at the camera lens to track 3D kinematics of passive markers on human participants or solid objects. $25,000 per camera plus software and accessories	3D reconstruction with multiple camera placements, continuous motion data streams, no wires or tethering, rapid visualization and output with extremely high accuracy.	Require software training/expertise, marker switching/dropout issues (line-of-sight), reflection interference.

Active Optical e.g. Optotrak	Active optical motion capture systems triangulate positions by illuminating one LED at a time very quickly or multiple LEDs with software to identify them by their relative positions. Rather than reflecting light back that is generated externally, the markers themselves are powered to emit their own light to track 3D kinematics of passive markers on human participants or solid objects. $45,000 per camera bank (3 cameras) plus software and accessories	Accurate reconstruction of 3D motion with no marker switching, continuous motion data streams, rapid visualization and output with extremely high accuracy.	Markers can be wireless from collection system, but wired from strober unit, markers are line-of-sight dependent.
Electromagnetic e.g. Fastrak	Electromagnetic systems calculate position and orientation by the relative magnetic flux of three orthogonal coils on both the transmitter and each receiver. The relative intensity of the voltage or current of the three coils allows these systems to calculate both range and orientation by meticulously mapping the tracking volume. $60,000	Positions and orientations simultaneously, no occlusion or line-of-sight issues.	Small number of markers, relatively expensive, tethered to a power supply, can be distorted by electromagnetic fields.
Inertial - Body Suit Xsens MVN	Full body motion capture suits that use individual inertial sensors on each body segment to track real-time 3D motion. $90,000 (includes 23 sensors, software, setup, and 1 day of training)	Occlusion-free, portable, large collection area, easy setup and use. Includes position information.	Lower positional accuracy, positional drift which can accumulate over time, most expensive.
I2M Inertial Motion Tracking, with HM Analyzer	Full body motion capture that uses individual inertial sensors on each body segment to log real-time 3D motion. $37,500 (includes 18 sensors and software)	Occlusion-free, portable, large collection area, easy setup and use. Less expensive than Xsens.	Lower positional accuracy, positional drift which can accumulate over time, logging (not wireless), no positional information.

5.1.13 Pressure Mapping

Tool	Summary Description	Pros	Cons
FSA: Pressure Mats	FSA offers various sizes of pressure mats, such as Hand Sensor Array (HSA) (hand-sized), and Seat and Back mats (larger sized). The mats come in an array (e.g. 8 x 8 array of 1" sensors) inside a flexible mat material. The system will provide a detailed recording of each sensors PSIU readings over time as well as a real-time display showing each sensors pressure (unless the system is being used in data logging mode). The maximum force that can be measured is 30 to 200 psi, depending on the system. $6650 for system plus $2000 per mat	Lower Cost than Tekscan Hi-Speed / Hi-Pressure mats	Lower Fidelity, lower maximum force, lower time resolution - not able to measure rifle recoil forces
Tekscan: High-Speed and High-Force Pressure Mats	Tekscan offers various sizes and solutions for pressure mats, including systems with higher capabilities for time resolution. The I-Scan System offers tactile pressure and force measurement capable of measuring up to 20 kHz. High Speed I-Scan is an enhanced version of the I-Scan pressure and force measurement system, that supports faster sensor scanning speeds (up to 20,000 Hz). The system is ideal for measuring high impact forces up to 30,000psi. $35,000	High-speed time resolution (able to measure rifle recoil forces)	Higher Cost
Tekscan: Prescale Pressure Measuring Film (Fuji Film)	Prescale film is used to measure contact pressures. The film structure consists of micro-encapsulated color forming and developing material. When pressure is applied to the film, a red	Very Low Cost	One-time use, static pressure measurements only, low fidelity

	color impression is formed in varying density according to the amount of pressure and pressure distribution. $57 per 8.5x11" sheet		
Nexgen: Intelligent Sensor Series	The Intelligent Sensor Series has various options typically in 16 sensor configurations. The Octopus format or configuration consists of 16 individual sensors that can be mounted anywhere. The Strip format/configuration is a series of 16 one-inch sensors. Similar to our other sensor products, the ISS configurations connect to the computer interface module for real time acquisition or via the computer interface that can gather and store sensing data separate from the computer. $6650 for system plus $5000 for sensor strip	Can target specific spots precisely, can instrument a tool	Lower fidelity than an pressure mat / array, because you are only looking at specific predetermined spots
Nexgen: Glove Pressure Mapping	The Glove Pressure Mapping System (GPMS) is a multi-sensor hand force data acquisition system that consists of an Ultrathin Glove Mat and a Computer Interface. The GPMS incorporates the ISS sensors in 20 and 24 sensor configurations. The sensor locations can easily be modified by the customer and are mounted using double-sided tapes. The individual sensors are covered with a Teflon coated laminate which makes them more durable. $6650 for system plus $6000 for glove	Standardized placement on hand without having to don/doff many sensors	Attaches to hand only (not tool)

5.1.14 Range of Motion

Tool	Summary Description	Pros	Cons
Analog Inclinometers	Uses ball technology that reduces the inclinometers sensitvity to vertical positions, 3" dial, provides reading to one degree, fluid damped. $90	Simple, readable, durable, inexpensive, short base for spine and long base for arm or wrist	Single sided, affected by gravity
Digital Inclinometers	Handheld unit, large digital display, stores measurements, presents max, min, and avg values. $280 (single), $525 (dual set)	Reduces examination time, enhances accuracy	More expen-sive

5.1.15 Soldier Performance Measures

Tool	Summary Description	Pros	Cons
Automated Target Scoring: Weapons Trainer	Speed and accuracy of target shooting can be measured by instrumented weapons that are tethered with an umbilical cable that supplies air effects, power, and communications with a virtual reality system.	Dynamic targets, realistic scenarios and targets, and no expenditure of ammunition. No safety risk or need for Range Safety Officer. Low set-up time - the system can be set up and left in a dedicated room.	Lower fidelity and lower realism when compared to actual shooting or combat situations. These systems are intended for training and not for scientific gathering of shot data. Usually a limited number of shooters at a time (e.g. 3 lanes at once). Scenarios are not typically set up for accurate shot timing information – instead, a combat scenario is presented for training.

Automated Target Scoring: Live Fire Systems	Speed and accuracy of target shooting can be done during live fire using an automated target scoring system. Participants fire at the target and acoustics are used to capture the accuracy and timing of every shot taken in a firing sequence.	Actual rifle firing (not simulation), very accurate results, ability to gather large amounts of data: many scenarios are possible with multiple participants on a multi-lane range.	Shooting is limited to a target range, not combat scenarios. A rifle range is required. These systems require considerable set-up.
Obstacle Course: CAN-LEAP (Canadian Load Effects Assessment Program)	The CAN-LEAP is used to study how the weight, bulk, and stiffness of a load placed on the infantry soldier affects combat performance. It is an obstacle course that is modular and consists of sequential test segments which are instrumented by Radio Frequency Identification (RFID) race timing mats. Additional stations can be added such as jump and weight transfer.	Accurate instrumentation - jump mats and RFID boxes with timing mats are used to precisely time the obstacles. Outdoor modular setup; can be stored and shipped as a unit.	Requires considerable setup, more expensive due to instrumentation and modularity.
Obstacle Course: Indoor (e.g. wooden structures at CFB Shilo, MB)	An indoor obstacle course is used to study how the weight, bulk, and stiffness of a load placed on the infantry soldier affects combat performance. They can be modular and can consist of sequential test segments. They can be instrumented at varying degrees of sophistication however the most basic form of measurement is by stopwatches.	Inexpensive, modular.	No accurate instrumentation other than stopwatches, low realism when compared to actual combat situations.
Obstacle Course: Outdoor Obstacle	An outdoor obstacle course is used to study how the weight, bulk, and stiffness of a load placed	More robust than indoor wooden structures, more realistic than indoor	Not modular, remains in place, no instrumentation other than

Course (e.g. at most bases)	on the infantry soldier affects combat performance. They are usually more rugged than indoor structures however they are set in place and not modular. They consist of sequential test segments, and can be instrumented at varying degrees of sophistication however the most basic form of measurement is by stopwatches.	wooden structures, relatively inexpensive.	stopwatches, low realism when compared to actual combat situations.
Combat Simulator: GRIIT (USMC Gruntworks Research Infantry Integration Testing)	The combat simulator is an indoor realistic environment that provides combat training using various scenarios displayed on screens in many different rooms. A wireless replica weapon is instrumented, and camera systems are used to measure time and accuracy of combat tasks and shooting. A control room allows for 3D virtual playback of the scenario (after action review).	Extremely realistic to combat scenarios. Instrumented with camera system that allows 3D playback in a virtual environment. Capacity for detailed analysis of every motion.	Not modular, high cost, not meant to test physical exertion limits.
VIRTSIM	VIRTSIM is a training simulator that immerses soldiers in a virtual reality environment, and has capacity to export data including 3D playback in a virtual environment, biomechanical forces/torques, and weapon firing data.	High realism to combat situation, allows 3D playback with capacity for detailed analysis, saves ammunition, no range required	Meant as a training system - the capability for data output (e.g. for biomechanical forces/torques or shot timing/accuracy on a target) is mentioned verbally by the company representative, but not advertised or confirmed. Not able to test physical exertion limits (e.g. crawl through a window)

5.2 Function: Measurement – System Integration

The function of system integration measurement included 3D environmental scanning, 3D handheld laser scanners, 3D point measuring, headforms, dummies, mannequins, and materials testing machines.

5.2.1 3D Environment Scanning

Tool	Summary Description	Pros	Cons
Leica HDS6200	Leica offers a product family of 3D environment scanners. For physical ergonomics applications (e.g. inside vehicle crewstations or workstations) a short-range "pulse" scanner (Leica HDS6200) is recommended. Range: 79m $80,000 to $100,000	High scan rate, resolution, range. Industry standard (Leica has over 50% of market share)	More expensive than other brands
Delta Sphere 3000	Laser scanner with lower cost, uses "time of flight" technology. Range 16m. $30,000 to $50,000	Cheaper than Leica	Lower resolution, range, scan rate

5.2.2 3D Handheld Laser Scanners

Tool	Summary Description	Pros	Cons
Creaform	Creaform offers a suite of portable, self-positioning handheld laser scanners, with a wide range of functionality and cost. Handyscan 3D scanners are completely portable, free standing, handheld scanners and are the only self-positioning scanners capable of generating real time STL files. This eliminates point cloud processing and the need to purchase costly tracking devices such as a CMM or measurement arm. Sales representatives suggested the Handyscan 3D scanners known as the	Large range of products, can chose the best one suited for our applications. High resolution and accuracy is possible.	Higher functionality products are more expensive than NDI VicraSCAN

	REVscan, EXAscan, VIUscan, MAXscan would most likely be suited for applied ergonomics applications. $42,900 to $76,900		
NDI VicraSCAN	VicraSCAN™ handheld 3D laser scanner is an all-in-one, self-positioning handheld 3D laser scanner. Using unique self-positioning technology and small reference targets, setup is a snap since no other tracking device is required. Simply plug the lightweight, ergonomic scanner into an available USB port and scan directly into powerful 3rd party software packages without the need to save and import data first. Truly portable, you can measure virtually anywhere with greater freedom and control using the VicraSCAN handheld 3D laser scanner. $48,000	Less expensive than Higher-end Creaform products, high resolution and accuracy	Only one product (not a family)

5.2.3 3D Point Measuring

Tool	Summary Description	Pros	Cons
Coordinate Measuring Machine (CMM)	A CMM is used to perform high accuracy 3D measurements of parts. In a R&D setting, they are typically set up in a laboratory and used for multiple applications (e.g. measuring prototypes). In a production environment, they are a programmed piece of machinery in an automated tooling system, and used to perform repeated quality control checks on parts. $20,000 to $500,000	High Accuracy and dependability. Measures without 3D CAD or virtual environment software.	Not portable, expensive, limitied size envelopes.
Portable CMM:	A portable CMM can be used for re-engineering workstations, vehicle	Portable, relatively less	Not as high accuracy as

Prodim Proliner	crewstations etc. The Proliner® has a measuring head that can be rotated in every direction and has a wire that can be stretched out for several meters. At the end of the wire is a metal measuring pen. With this measuring pen you can simply mark the relevant points. These points are directly translated into a digital DXF CAD file. $25,000	expensive	a stationary CMM since it is a hand-held pen
FaroArm	The FaroArm is a portable Coordinate Measuring Machine (CMM) that is used to perform high accuracy 3D measurements of parts. Unlike the Proliner the arm has the ability to measure around corners. Faro recommends the "Fusion" for physical ergonomics applications because accuracy is OK at .001 inches (i.e. we are not doing precision machining). The 8 foot / 7axis arm is recommended. It has a 6"x6" mounting surface. A product demonstration is recommended. Cost: a) Could be outsourced for each job b) Probe system: $52,000 ($35,000 for arm, $15,000 for software, mounting, and on-site training, $2000 for mounting with magnetic base) c) Probe and Scanner attachment (for surface scanning): $74,000 ($35,000 for arm, $20,000 for software, $17,000 for scanning head, $2,000 for mounting)	Ability to measure around corners and vehicle seats	May be too large to easily fit in tight spaces like a vehicle crewstation

5.2.4 Headforms, Dummies, and Mannequins

Tool	Summary Description	Pros	Cons
NOCSAE Headform	A biofidelic headform with a glycerin-filled brain cavity. It is intended for drop testing for impact injury assessment, according to a NOCSAE laboratory protocol.	Glycerin filled brain cavity, standard for sport helmet impact testing	More expensive than a general purpose headform

Vehicle Crash Testing ATDs	Full-body ATDs (Anthropometric Test Dummies), standard for motor vehicle crash testing. They are instrumented to show compliance to government regulations in a crash test.	Dynamic instrumentation for crash tests, adheres to government regulations for vehicle manufacturing	More expensive than general purpose dummies, specifically made for automotive industry
ISO Headforms	ISO Headforms are meant for impact testing of US and Canadian Industrial Headwear. The cast urethane half headforms are used for impact attenuation testing. It is designed and manufactured to meet ANSI Z89.1 and CSA Z94.1 safety helmets standards.	Standard for Industrial Headwear in US and Canada	Only top half of the headform, not meant for any other application
General Purpose Dummies	General Purpose dummies are a low cost alternative to the various dynamic crash test dummies. These dummies expand the role of the anthropomorphic test device into many areas beyond vehicle crash testing. Since dynamic performance testing is not necessary the dummies may be produced economically.	Less expensive than Vehicle ATDs, more biofidelidy than mannequins, more rugged than mannequins	Does not have any instrumentation, does not adhere to government codes
Mannequins	Mannequins are a lower cost alternative to general purpose dummies, if biofidelity is not important. They can be useful for taking photographs of equipment on a baseline featureless human shape.	Inexpensive, good base for photographs.	Low biofidelity, incorrect mass properties
Rescue Randy	Rescue Randy was developed for lifelike adult or juvenile victim handling, transportation, and extrication training. It has mass and shape biofidelity.	Has mass and shape biofidelity, more rugged than mannequins	No instrumentation.

5.2.5 Materials Testing Machines

Tool	Summary Description	Pros	Cons
Tension and Compression	Instron 5900 series are machines to evaluate compressive and tensile loading primarily on medical devices and applicable materials.	Various models available to fit desired applications, simultaneous data acquisition on load, extension and strain channels, customizable control panel	Requires many specialized uses to offset purchase and setup
Torsion	Instron MT series are machines to evaluate torsional loading on a range of materials from metals to plastics to biomaterials.	Range of low-capacity torque cells are available down to 0.225 Nm (2 lbf-in), torsion testing software offers easy test set up, graphical data plots, automatic calculation of desired test results and flexible reporting tools	Limited applications compared to multiaxial testers
Multi-Axial	Multi-axis testing systems provide the ability to more closely simulate the real-life performance of various parts and components. They eliminate the need (and associated cost) for having multiple materials testing machines in a single laboratory setting.	Testing in multiple axes, eliminates need for multiple machines, dynamic force capacity, versatile T-slot table for regular and irregular grips and specimens	Requires many specialized uses to offset purchase and setup

5.3 Function: Virtual Modeling

The function of virtual modeling included analytical biomechanics, digital human modeling with force and torque outputs, digital human modeling with ROM and spatial outputs, and video analysis for time and motion studies.

5.3.1 Analytical Biomechanics

Tool	Summary Description	Pros	Cons
Hand Calculations	Use of first principals to determine a solution. This could be in the form of muscular loading, applied force at a particular joint, or muscular fatigue based on % of MVC.	Able to get a general solution that will show if a more complex simulation is in the correct range. Inexpensive.	Low fidelity, takes time to search for the proper equation to apply, often requires many assumptions - a general range of solutions is the only output, often no first-principals methods exist for a particular application

5.3.2 Digital Human Modeling with Force and Torque Outputs

Tool	Summary Description	Pros	Cons
Siemens PLM - JACK	Digital Human modeling and simulation for virtual products and work environments. Able to size human models to match worker populations, as well as test designs for injury risk, user comfort, reachability, line of sight, energy expenditure, fatigue limits $31,000 plus $5,000 per year	Superior hand model, 100s of anthro sizes, able to do many (generic) biomechanical tests and evaluate strength requirements for many dynamic tasks. Motion capture toolkit.	Expensive?
Santos	Human modeling technology that predicts human posture and motion for avatars in a physics-based 3-D environment. Constraints	Specialized modules for hand and clothing. Posture prediction. Ability to pay Santos Human Inc. to customize for our	Not standalone software - reliant on Santos Human Inc. to develop for a particular application.

	include gravity, muscle fatigue, muscle strength, clothing fit, material properties and use of predictive dynamics. $ - Cost information not available because it depends on the application and how Santos Human Inc. will develop the software.	needs. Physics engine and optimization-based approach to motion prediction.	Optimization for motion prediction not validated.
Digital Biomechanics	Simulation tool to model the effect of equipment on soldiers engaged in actual tasks, from walking, running, and crawling to completing a virtual obstacle course. The models obey laws of balance, locomotion, and dynamic loading. $80,000 plus approx $30,000 to get a scenario developed.	Customized for military applications, already has military contracts. Will develop for customized needs.	Limited Anthropometry. Not standalone software - reliant on Boston Dynamics to develop any motion/scenario for an application. Relatively expensive. User has no motion capture input. Little evidence of validation for the motion and forces.
Madymo	Impact injury biomechanics software for analysing and optimizing occupant safety designs. $15,000 plus yearly subscription	Specialized for impact injury and the automotive domain. Very high fidelity.	Focused on impact injury, specific to simulation of humans in a vehicle. High learning curve - typically requires advanced crashworthyness and programming knowledge to use.
Dassault Virtual Human (Delmia, formerly Safework)	Digital Human modeling for determining the performance of people in a workplace, and interaction with a product. Includes task simulation, activity analysis, posture analysis, measurements editor, and vehicle	Same parent company as SolidWorks, standalone software, seems to have more capabilities than others (e.g. ROM, FOV and vision analysis, activity analysis, posture analysis,	Expensive? No biomechanics toolbox – no way of calculating forces or torques.

	occupant accommodation. $15,000 to 50,000 depending on configuration	measurements editor), able to have multiple humans in the same simulation	
Ramsis	RAMSIS is the standard solution for designing vehicles and aircraft from an ergonomic standpoint. This leading CAD manikin enables efficient analyses covering the topics of vision, comfort and ergonomics based on a globally unique anthropometric database. $28,500 to $50,000 depending on configuration	Same parent company (Human Solutions) as the Vitus Smart 3D Scanner, specialized in vehicles and vehicle controls	Expensive? Focused on the seated occupant.
Anybody	Modeling system for mechanics of musculoskeltal system. User can impose any kind of posture or motion, also inputs motion capture data. Output is muscle/joint forces, elastic energy in tendons, antagonistic muscle forces. $34,000 plus $6,000 per year	High fidelity dynamic muscular simulations, focused on musculoskeletal system. More validation has been done than other software packages.	No FOV, no vision or reach analysis, cannot import/export CAD files. Lack of library of digital humans from Anthro database.

5.3.3 Digital Human Modeling with ROM and Spatial Outputs

Tool	Summary Description	Pros	Cons
HumanCAD Mannequin Pro	HumanCAD is a human modeling solution that creates digital humans in a three-dimensional environment in which a variety of ergonomic and human factor analysis can be performed. HumanCAD aids users with the design of products and	Lower Expense, can do spatial analyses (ROM, FOV) with a large anthro database	Lower fidelity, can not do real-time dynamic force / torque outputs during dynamic movements,

	workplaces by determining what humans of different sizes can see, reach or lift. $12,000		static analysis only
SolidWorks	SolidWorks is one example of a 3D CAD modeling software package. While not intended specifically for virtual modeling of digital humans, some amount of analysis can be done by bringing solid parts of digital humans into the virtual space and analysing the interaction with equipment. Analyses can include ROM and FOV as well as equipment compatibility. $6,000 plus $1,500 per year	Ability to import industry-standard parts/workstations. The HumanCAD software works well with SolidWorks.	Not intended for digital human modeling and therefore not much exists for solid models of humans, anthro, inputs, outputs

5.3.4 Video Analysis for Time and Motion Studies

Tool	Summary Description	Pros	Cons
Kinematic Analysis Software	Software packages designed for the elite coach, elite athlete, sports scientist, podiatrist, physiotherapist or biomechanist to provide rapid feedback from recorded video and allow analysis of dynamic motion patterns, potentially awkward joint postures, and inconsistent movement in repeated trials in athletic, laboratory or occupational tasks. $4,000	Easy-to-use and economical solution for static or quasi-static biomechanical analysis, available with a range of functionality and price-points	Variable level of accuracy and repeatability, only offer analysis in one plane of view
2D Biomechanical Analysis Software	Custom Software packages with the ability to calculate acute and cumulative loads at the major body joints, particularly the lumbar spine region. They can be used to estimate the risk of injury associated with a variety of occupational actions including pushing, pulling, lifting, lowering, holding, or carrying.	Rapid calculation of acute and cumulative joint loading based on literary joint characteristic databases	Not typically commercial-ly available, confined to academic use

6. Mapping Project Needs to Tools

Findings from Project Needs showed that the most needed physical ergonomics tools were in anthropometry (traditional anthropometric measurement, clothed anthropometry, and 3D scanning), environmental scanning, modeling and simulation, and motion capture. This section recommends tools based on the State-of-the-Art review. For tool groups where the State-of-the-Art review did not provide a clear recommendation, a way ahead for further evaluation of tools is proposed.

6.1 Anthropometry

Rudimentary tools for anthropometry include a traditional measurement kit, anthropometric databases, and statistical software. The GPM Large Instrument Anthropometric Kit is recommended. Although it is the most expensive, it is recommended above the others because it is robust, trusted as the industry standard, and is capable of doing height measurements. In addition, the authors of this report have found it to be suitable for military field trials. For clothed anthropometry, custom elongated blades should be procured (as shown in Figure 2) so that participants could be measured while wearing bulky clothing such as fragmentation protective vests with plates.

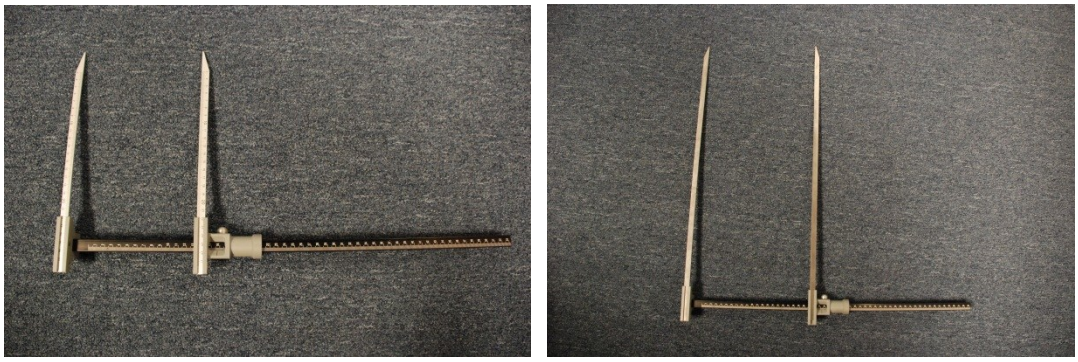


Figure 2: GPM Anthropometer with Standard Blades (Left) and Custom Elongated Blades (Right)

For 3D body scanning, we recommend the Human Solutions Vitus Smart system. While it is relatively expensive, it appears to be the most up-to-date technology with high accuracy resolution, a large scan volume, and sophisticated software that automatically outputs 140 anthropometric measurements in a single scan, that are consistent with ISO and ANSUR measurement requirements. One weakness of the Vitus scanning system is that it takes 12sec to capture the entire body scan and it is possible that the subject's breathing or body sway may introduce error. However, Human Solutions argues that ergonomic measures are primarily interested in horizontal slices, and the error from movement at any given instant is not great since the scanner progresses from the top down. The Vitus Smart is quite repeatable as long as subjects are relaxed - chest and belly circumference having the greatest variation. Reports indicate that the Vitus system still remains more precise and repeatable than manual measurements.

When comparing the Human Solutions scanner to the [TC]2 system, the Human Solutions system is significantly more expensive, however the [TC]2's lower resolution, small scan volume, and the limitations of the software shift the decision in favour of the Vitus system. Although the [TC]2 would be suitable for applications with lower accuracy requirements and a smaller scan volume, our needs analysis suggests that the requirement for multiple scan postures (e.g. seated and reach) and the desire for fully clothed scans requires a larger scan volume, beyond the [TC]2's capacity. The 3dMD does not have automatic anthropometric outputs, and getting measurements from the 3D image after capture appears very analyst-intensive and time-consuming. While the 3dMD system can acquire near-instantaneous scan captures, this benefit does not outweigh the manual workload concerns with scan possessing.

6.2 Modeling and Simulation

Warfighter modeling and simulation tools for assessing physical ergonomic characteristics of clothing/equipment, crew spaces, and so on, tend to be mix of specialized military software models and generalized commercial products.

Specialized military software models such as Digital Biomechanics and Santos offer considerable potential as they continue to develop and validate functional modeling capabilities and their respective range of toolsets to support investigation and analysis. Digital Biomechanics has been used in the SIHS TDP for prototype design, evaluation, and downselection through biomechanical analysis, range of motion assessments, weapons and equipment compatibility with dynamic motion, and so on. However, while Digital Biomechanics does provide considerable analytical capabilities, it also requires a considerable setup time to create new scenarios or new projects, and can require further programming work and MatLab for new analyses types. Often these new movement scenarios and analyses require contracting back to Boston Dynamics. Currently, motion scripts must be first derived through human motion capture techniques to provide the necessary movement scripts in the Digital Biomechanics software model. The Santos product also has a lot of potential and compelling photorealistic human models but existing users of the software have suggested that it is still very much a developmental research tool that is still some way from realizing the potential being advertised. In both cases, these software tools are some way from achieving a finished product that is readily usable without extensive training and product support.

At this point in time, generalized commercial products offer the best solution for meeting the broad range of applications identified in the Needs analysis. For simple, straightforward analyses, HumanCAD provides an easy-to-use tool to support static user-centred design and analysis of products and workstations. Analysis of reach envelopes and field of view are possible with the digital human in stationary postures. While HumanCAD would be useful on a number of projects, it lacks dynamic analysis, and detailed human manipulation.

According to the Needs analysis, dynamic motion of the digital human is necessary, and a more versatile software package than HumanCAD is required. We believe that Siemens's JACK offers a good solution at this time. A trail version of JACK was obtained and found to be functionally better than HumanCAD due to its greater precision, many more features, dynamic motion capabilities, and more extensive options for human model manipulation. The advanced anthropometry feature allows for choice of human model scaling, manipulation of 25 anthropometric values, as well as the automatic use of numerous

anthropometry databases. Additionally, there is a motion capture toolkit that allows for motion capture data from a subject in a physical mock-up to be collected in real time, integrated into the virtual scene in real time, and then presented back to the subject with a binocular display so that they perceive that they are immersed in the virtual environment so that they can better visualize and interact with a design with a space. While JACK may not be as photorealistic as some other products, we feel it is the best option at this time to meet the identified Project Needs.

For further information, a review of JACK was completed by DSTO (Blanchonette, P., 2009), and a detailed review of current software is presented in the Handbook of Digital Human Modeling (LiFiandra, M., 2008).

6.3 3D Environmental Scanning

The Needs analysis identified a number of projects/programs that would benefit from a rapid, precise capability to capture 3D models of interior and exterior spaces. There are a number of 3D Environmental Scanning tools available to accurately and quickly reproduce a workstation, vehicle crewstation, item of equipment, or any workspace for inclusion in a virtual environment. The choice of tool often depends on the size of the item or area to be scanned. For larger environmental workspace digitization, the Leica HD6200 appears to be the most suitable technology for the precision and quality demands of applications of interest. However, a product demonstration from Leica and DeltaSphere would be beneficial to better understand how this technology could best be employed. To digitize smaller components such as controls or pedals, a hand-held laser scanner would be an effective option with high precision and photorealism. The Creaform hand-held scanners have proven to be effective in other DRDC projects. Mid-sized workstations and equipment that are too small for an area scanner but too large for a hand scanner would benefit from a 3D point measurement device like a FaroArm where referential points in 3D space can be recorded and used to anchor other smaller hand scanned segments.

6.4 Motion Capture

The capability to capture human motion during key movements and actions would be beneficial for a number of projects/programs that need to investigate the effects of a design on human movement and the effects on actions in confined crew spaces. Often these motion capture scripts would be used to drive a digital human model in a virtual environment. Traditionally this has been done with optical systems, however, increasingly, inertial motion tracking systems are proving their value due to their versatility for use in indoor and outdoor (full sun exposure), their short duration set-up requirements, portability, lack of occlusion effects, and large capture areas. An inertial motion tracking system is recommended because it will allow for greater versatility when collecting motion capture data. Additionally, projects that involve vehicles will benefit from an inertial system because the human will be able to ingress a vehicle and perform tasks inside the vehicle that would normally be occluded by an optical system. We recommend the full featured XSens Biomech system due to its precision, real time wireless data capture and display, wide array of recorded and derived biomechanical data, and its ability to replay the capture output in other virtual software models like JACK.

7. References

Blanchonette, P. (2009). *Jack Human Modeling Tool: A Review*. DSTO Defence Science and Technology Organisation, Australia.

LaFiandra, M. (2008). *Methods, Models, and Technology for Lifting Biomechanics.* Handbook of Digital Human Modeling, pp 8-16 to 8-25, Edited by Duffy, V., CRC Press.

Annex A: Detailed Tool Information

This Annex includes manufacturer's descriptions, pictures, technical specs, website links, costs, and other relevant technical information. The numbering system in this Annex matches the heading numbering in the State-of-the-Art Review summary (Chapter 5).

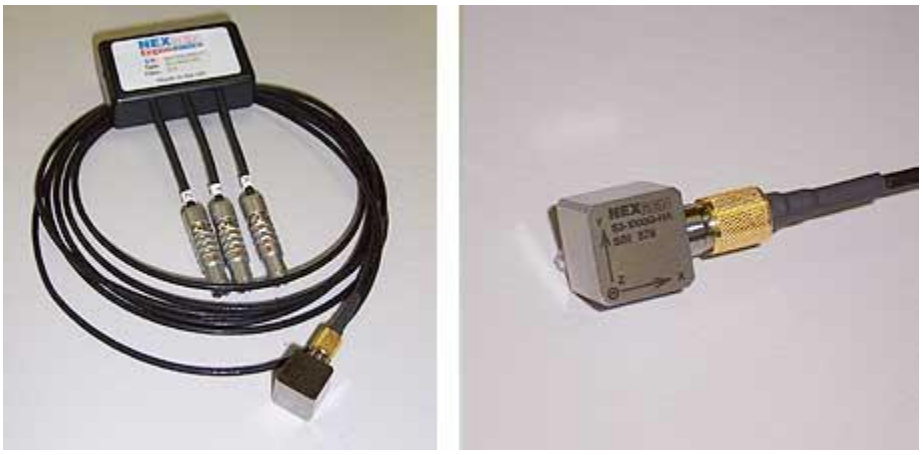
5. Measurement: Human

5.1 Function: Measurement - Human

5.1.1 Accelerometry

5.1.1.1 NexGen Ergonomics Series 3 Tri-Axial Accelerometer

Three-axis accelerometer as part of the NexGen Vibration Analysis Tool Set (VATS). These sensors offer real-time collection of 3-axis accelerations that avoid the problems of differentiation and line-of-sight dependence that motion capture and goniometer systems have. They are useful for clinical, laboratory or occupational settings looking at anything ranging from body segment movements, joint angles, reaction forces, and mechanical vibrations. The accelerometers plug into a wireless DataLOG system.



NexGen Series 3 Tri-Axial Accelerometer

Range: ± 1000 G
Low-Pass Filter: 1,250 Hz, 2,500 Hz, 5000 Hz, user adjustable via links by removing lid of interface unit
Voltage Output: ± 1 V
Linearity: 1% FSO
Sensitivity: ± 2%
Temperature Range: -40 to +175 °C
Size (LxWxH): 0.54” x 0.51” x 0.54”
Weight: 8g
Cost: $2000 to $2400 per accelerometer, plus $6500 for DataLOG with software, plus Hand-Arm mounting accessories.
Brochure: No

Website: http://www.nexgenergo.com/ergonomics/vats.html

5.1.1.2 Noraxon 3D Accelerometer

The Noraxon (Scottsdale, AZ, USA) 3D Accelerometer is a compact and lightweight acceleration sensor especially designed for use with human and animal surfaces and body segments. Due to its size and mass, it is easy to attach and provides accurate data. Attached to non biological material and bodies, it can measure impact forces up to 6G (Standard) or up to 16G (optional version). The sensor construction guarantees an effective use in a variety of application areas, such as medical research, sports analysis, rehabilitation, ergonomics and robotics. It can be used to detect ground contact (heel strike) in walking and running, motion vibration in medical tremor analysis or impact and shock impulses in sports specific equipment or ergonomic tools. These sensors are specifically designed for use with a Noraxon physiological data collection system (eg. EMG system).

Noraxon 3D Accelerometer

Output Range: +/- 2g , +/- 6g
Voltage Output: ± 5 V
Sensitivity: 2g: +/- 2 V/g 6g: +/- 0.67 V/g
Bandwidth: 5Hz – 1.8kHz
Operating Range: 0 - 70°C
Size (LxWxH): 2.03cm x 1.52cm x 0.76cm
Cable Length: 1m
Cost: $1000 for accelerometer, plus approx. $9500 for Noraxon data collection system and software
Brochure: Yes – PDF *Website*: www.noraxon.com

5.1.1.3 BioPac Systems Tri-Axial Accelerometer

The BioPac Systems (Goleta, CA, USA) tri-axial Accelerometers are high level output transducers that provide three outputs, simultaneously measuring acceleration along the X-, Y- and Z-axes. The transducers can be used on any part of the body or attached to external equipment. The pliable and unobtrusive design conforms readily to body contours. They come with a Velcro strap for easy attachment. The frequency response extends from DC to 500 Hz. The accelerometers are extremely accurate and can easily be calibrated by simply changing their orientation in three-dimensional space, so that gravity (G=1) acts only upon the desired axis. The TSD109 series accelerometers connect directly to the HLT100C High Level Transducer module.

BioPac Systems Tri-Axial Accelerometer

Range: Force sensing ± 50 G; Wireless transmission 5 to 10m
Scale Factor: 38 mV/G
Bandwidth: DC – 500 Hz (-3 dB)
Non-linearity: 0.2% FSO
Size (LxWxH): 33mm x 28mm x 19mm
Weight: 17g
Cable Length: 3m; but wireless is available ($1500 in cost estimate)
Cost: $7100 for accelerometer, wireless receiver, data collection system and softwares.
Brochure: No *Website*: http://www.biopac.com/triaxial-accelerometer-50g

5.1.1.4 Onset: Hobo Pendant Accelerometer

The HOBO Pendant G Acceleration Data Logger is a waterproof, three (3) channel logger with 8-bit resolution that can record up to approximately 21,800 combined x-, y-, and z-axis acceleration readings or internal logger events. The pendant logger uses a coupler and optical base station with USB interface for launching and data readout by a computer.

The pendant G data logger can be used for a wide variety of experiments, demonstrations and field studies by measuring dynamic acceleration resulting from motion, shock or vibration. It can also detect static acceleration of gravity, making it possible to measure tilt, inclination, and position.

The logger uses an internal three-axis accelerometer with a range of ±3G based on micro-machined silicon sensors consisting of beams that deflect with acceleration. These beams are arranged to act as a variable capacitor. As the beams flex, the capacitance changes proportionately. This capacitance change is converted to voltage, filtered and measured by the logger, and displayed in the software in units of g-force.

The HOBO Pendant G Logger Kit includes:

- Pendant G Data Logger (#UA-004-64)
- HOBOware Lite Software (#BHW-LITE)
- Optic Base Station and Couplers (#BASE-U-1).

Onset: Hobo Pendant Accelerometer

Number of Channels	Selectable 1, 2 or 3
Measurement Range	±3G
Accuracy	±2.5% FS at 25°C (77°F) Factory Calibrated
8-bit Resolution	0.025 G, 0.24m/sec^2 (0.8ft/sec^2)
Memory	64K Measurements (approx 21.8K combinedd x,y,z axis readings or events)
Logging Interval	NORMAL mode: 1 sec to 18 hrs

	FAST mode: 0.01 sec to 0.99 sec (user-selectable)
Download Speed	30 seconds via Optic USB for 64K memory
Time Accuracy	±1 min/month at 25°C (77°F)
Battery Life	NORMAL mode: 1 year typical use FAST mode: 7 days @ 100Hz Sampling user-replaceable
Operating Range	-20°C to 70°C (-4°F to 158°F)
Environment	Waterproof to 30 Meters (100 ft)
Durability	Drop-proof to 1.5 Meters (5 feet)
Standards Compliance	CE
Dimensions	58mm x 33mm x 23mm (2.3" x 1.3" x 0.9")
Cost	$75 per accelerometer $150 for accelerometer kit that includes software and accessories
Brochure?	No
Website:	http://www.microdaq.com/occ/pendant/pendant_g_data_logger.php

5.1.2 Anthropometry: Traditional

5.1.2.1 Centurion Measuring Kit

The Rosscraft line of Campbell calipers are named after the late Mr. Robert Campbell, the inventor of the double siding branch principle, an exclusive Rosscraft design feature of Anthropometric Devices. The Rosscraft caliper may be the only caliper manufactured in the world that has long branches that do not bind under pressure at the tips. Rosscraft is responsive to scientists and health professionals. The Centurion Kit reflects a consensus of what is required for comprehensive anthropometry for individual and team deployment. The Centurion Kit consists of the Campbell 20 wide sliding calipers, Campbell 10 small bone calipers, Segometer 4, Head square with tape, 2 Slim Guide Skinfold Calipers, 2 Steel anthropometric tapes, anthropometric fundamental cd, and a cordura carrying case.
• 1 Campbell 20 (54 cm) wide sliding caliper • 1 Campbell 10 (18 cm) small bone caliper • 1 Segmometer 4 • 1 Head square with tape • 2 Slim Guide Skinfold Calipers • 2 Steel anthropometric tapes • 1 Anthropometric Devices Fundamentals CD • 1 Cordura carrying case - LWH 70 x 35 x 10 cm 3.5 kg
Cost: $1,529.95 USD
Advantages: comprehensive kit, relatively inexpensive
Disadvantage: unknown construction and materials, durability unknown, not large enough for height measurement
Manufacturers: Centurion Distributer: QuickMedical Website: http://www.quickmedical.com/anthropometry/centurian_kit.html Brochure? No

5.1.2.2 GPM (Distributed by Seritex Inc) Large Anthropometry Kit

• #101 Anthropometer • #102 Curved Crossbars for the #101 • #104 Sliding Caliper • #106 or #107 Spreading Caliper with rounded (#106) or pointed (#107) ends • #111 Measuring Tape
Cost: $7,243.00 USD
Advantages: The gold-standard kit, robust, durable
Disadvantage: Relatively expensive ($7243)
Manufacturers: GPM Distributer: Seritex.com Website: http://seritex.com/gpm Brochure? No

5.1.2.3 Mentone Educational Centre Anthropometer Measuring Set

Professional Anthropometer Measuring Set (PE036)

Research quality instruments of the finest tool steel for measuring stature, length of limbs, depth and width of chest, dimensions of facial structures and more.

This set has been manufactured to faithfully meet the basic rules of anthropometry developed by R. Martin, the author of the "Textbook of Anthropology". It is an ideal set of instruments designed to make objective and quantitative measurements on the size and form of various parts of the human body.

As these instruments were originally designed for anthropological purposes, it may take time to understand how to use them effectively. The pamphlet included explains the essential points needed to gain measurements, but leaves further explanations to more specialized literature (not included). When it is necessary to achieve consistent results on subjects, please be certain to make reference to more specialized literature.

This kit contains a selection of instruments that will make it possible to obtain measurements from your subject.

- Instruments for measuring distances in straight lines
- Instruments for measuring curves and circumferences
- Instruments for measuring thickness

The Anthropomometer Measuring Kit has been designed to remain faithful to the original basic rules, but also to include instruments used most frequently.

- Anthropometer consisting of 4 pipes, made of brass 0 - 1950mm
- Rod Measures, straight rules 0 - 270mm, curved rules 0 - 280mm
- Tasterzirker Callipers, brass 0 - 450mm
- Gleitzirkel Martin's Thickness Gauge, stainless steel/brass 0 - 200mm
- Stainless steel rule, 0 - 150 mm
- Stainless steel tape measure, 0 - 2000mm
- Finger Sterilizing Case, and
- Sturdy Carrying Case

Cost: $2,970

Advantages: Comprehensive Kit, hard case, cheaper than Seritex GPM Kit, apparently durable construction

Disadvantage: No base plate for anthropometer

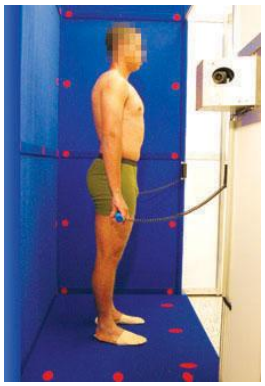
Manufacturers: Mentone Educational Centre

Website: http://mentone-educational.com.au/products/physiology/equipment/goniometer/pe036

Brochure? Yes

5.1.3 Anthropometry: 2D Photogrammetry

5.1.3.1 Body Scanning System for the 21st Century

Body Scanning System for the 21st Century (BoSS XXI) The system captures three simultaneous high-resolution images of an individual, from the top, front and the side. In seconds, the proprietary image processing software measures his or her body. Then, using sizing rules customized by your designers, BoSS-21 recommends the correct size of the garments and equipment you specify. BoSS-21 can be customized to work in any language, and to interface with any existing IT infrastructure.
● Fast: image acquisition takes only a fraction of a second, and the body measurement and garment sizing is completed in seconds ● Accurate: more reliable than measures repeated by different anthropometric experts ● Dependable: no moving parts, requires almost no maintenance Cost effective: constructed using off-the-shelf commonly available technology ● Easy to operate: requires no special knowledge or training ● Private: ○ BoSS-21 is much less invasive than traditional methods ○ Imaging is done in an enclosed chamber ○ Faces are pixilated automatically before being displayed ○ No images are stored to disk ○ BoSS-21 is a stand-alone turnkey solution that can operate independently, or as part of an IT network.
Cost: Developer Edition (stationary and portable): $59k each Standard Edition(stationary and portable): $54k each BoSS-21 Developer Edition + BoSS-21 Portable Standard Edition: $86k

Prices include installation, training, 1 year technical support (labour and parts) + 1 year warranty
Advantages: ● Reduces high rate of return of poorly-fitted garments ● Reduces frequency of unnecessary alterations ● Creates and updates a database of both body dimensions and garment size requirements of current Forces personnel ● Optimizes inventory management and logistics: inventory is acquired based on the needs of the actual personnel on hand, inventory levels can be minimised, and costly last-minute acquisitions can be avoided ● Provides accurate data for the construction of custom garments and personal equipment.
Disadvantages: • 2D (not 3D) • Inferential algorithms may not be precise • Only 14 direct measures
Manufacturers: VisImage Website:http://www.vis.ca Brochure? Yes

5.1.4 Anthropometry: 3D Laser Scanning

5.1.4.1 Human Solutions: Vitus Smart XXL

VITUS Smart XXL The VITUS Smart XXL is a 3D body scanner created to achieve a high degree of accuracy in the measurement of body dimensions, in accordance with the international DIN EN ISO 20685 standard. This four-column scanner is especially suitable for serial measurements and for the size fitting of workwear. (Note the Vitus Smart LC was the precursor and is now discontinued)
Specifications • Measurement principle: optical triangulation (laser technology, safe for the eyes) • Sensor heads: 8 • Measuring range: height Z: 2100 mm; base X: 1000 mm; width y: 1200 mm • Accuracy: cylindrical tube, 110 mm. in diameter and 2100 mm. in height, at constant

temperature conditions of between 15° and 30°C
- Average max. error (circumference) = < 1mm
- Measuring time: approx. 12s
- Density of points: 27 points/cm2
- Export: data can be exported in ASCII, OBJ, STL and DXF formats

Dimensions:

- Exterior dimensions: height: 2950 mm; base: 2200 mm; width: 2200 mm
- Floor space requirements: 4.84 m2 (square floor space area)
- Total weight: 250 kg
- Power supply: 230V / 50Hz; 115V / 60Hz; 420 VA

Also: Head scanner, consulting services are available.

Cost: $233,300 (includes all hardware, software and services)

Advantages:

Very accurate, stable, very high resolution, large scan-space to facilitate non-typical postures and garments, software allows for multiple postures (i.e. take two scans and stitch them together) and semi-automatic measurements (scans can be compared to manual measurements and body landmarks). Meant for research (other clients include US and German defence research). Can put the participant on a clear plastic platform for non-standard postures. Outputs directly to RAMSIS for 3D simulation (e.g. for draping a garment on a digital human in a simulation).

Software outputs 140 automatic anthro measures, and can be customized for other automatic measures depending on the application and protocol.

Disadvantage:

Relatively expensive, long scan time (not as precise as 3dMD)

Manufacturers: Human-Solutions

Website: http://www.human-solutions.com/apparel/technology_scanning_vlc_en.php

Brochure? No

5.1.4.2 [TC]² NX-16

[TC]2 NX-16

The NX-16 3D scanner scans the whole body in seconds and rapidly produces a true-to-scale 3D body model. The included automatic body measurement software can extract over 400 unique measurements many of which can be user customized. The 3D scanner is world leading in terms of price, small size (4x5 feet), ease of use, subject privacy and safety (no lasers or radiation sources).

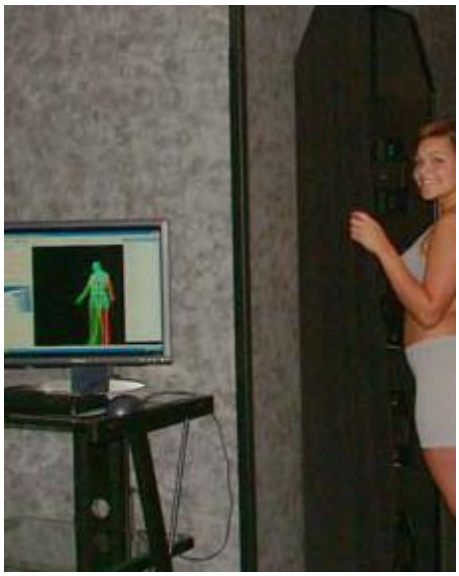
High-fidelity, accurate, realistic avatars can be created from body scan data, or through the use of [TC]²'s avatar engine with the input of a few basic measurements. The NX-16 now features capabilities for Virtual Fashion visualization with links to 3D garment content from major industry CAD packages.

Specifications

- White-light scanning technology
- Extremely small physical volume
- Safe, private self-scanning mode
- Data acquisition in seconds
- Hundreds of automatic measurements
- Automatic Avatar generation
- Face-color from photo

Cost: $37,500 (includes all hardware, software and services); $5000/year for full maintenance (optional)
Advantages: Compact size, relatively inexpensive, automatic avatar generation.
Disadvantage: Relatively small Scan Space, lower resolution, software only allows for one posture, cuts of bottom of legs, meant for apparel industry
Manufacturers: [TC]^2 Website: http://www.tc2.com Brochure? Yes

5.1.4.3 [TC]^2 LC-16



[TC]2 NX-16 The newly-introduced LC-16 is a lower-cost version of the NX-16, which has identical physical properties and technology as the NX-16. The LC-16 3D scanner scans the whole body in seconds and rapidly produces a true-to-scale 3D body model. The included automatic body measurement software can extract over 400 unique measurements many of which can be user customized. The 3D scanner is world leading in terms of price, small size (4x5 feet), ease of use,

subject privacy and safety (no lasers or radiation sources). High-fidelity, accurate, realistic avatars can be created from body scan data, or through the use of [TC]²'s avatar engine with the input of a few basic measurements. The NX-16 now features capabilities for Virtual Fashion visualization with links to 3D garment content from major industry CAD packages.
Specifications • White-light scanning technology • Extremely small physical volume • Safe, private self-scanning mode • Data acquisition in seconds • Hundreds of automatic measurements
Cost: $27,500 (includes all hardware, software and services); $5000/year for full maintenance (optional)
Advantages: Compact size, relatively inexpensive.
Disadvantage: Relatively small scan space, lower resolution, software only allows for one posture, cuts of bottom of legs, meant for apparel industry
Manufacturers: $[TC]^2$ Website: http://www.tc2.com Brochure? Yes

5.1.4.4 3dMD

3dMD

3dMD's imaging systems are the most widely used ultra-fast, high-precision 3D surface imaging devices in leading teaching institutions, hospitals and private practices worldwide.

The 3dMDbody System is a highly flexible configuration that allows for a large number of variations in camera positioning and lenses. A customer can purchase our standard fixed model for the practice or clinic, or the 3dMDbody FLEX8 System, which enables the user to configure and reconfigure the modular units to fulfill a number of different capture tasks and coverage variations with a simple calibration

process. The image capture time remains 1.5 milliseconds in line with 3dMD's simpler face system, yet the 3dMD image generated retains equivalent medical accuracy and high resolution texture maps. In certain configurations more than one million polygons are automatically generated raw from the machine. Moreover, with the FLEX package, the 3dMDbody System can be reconfigured as one or more capture devices such as two 3dMDcranial4 systems, multiple 3dMDface Systems, or a 3dMDtorso4 System and a 3dMDcranial4 System

Specifications

- Coverage: 360-degree capture of body from head to toe
- Capture speed: ~1.5 milliseconds at highest resolution
- Geometry Generation: One continuous point cloud produced from the four or eight stereo camera viewpoints, which eliminates the data errors associated with merging / stitching data sets together
- Option for simultaneous acquisition of geometry and high resolution texture, or geometry only
- Lighting requirements: operates in standard clinic/office lighting conditions

Cost: $244,000

Advantages:

Very high speed – much more accurate than other systems (e.g. the human can move around in 12sec (Vitus scan) but the 1.5ms is almost instant capture)

Freezes human motion (whole body in 1.5 ms) so it is very precise (e.g. for fitting eyewear or gas masks). Large scan-space to facilitate non-typical postures and garments, high volume scanning, very accurate, high resolution, software allows for multiple postures and landmarking. Meant for research (including defence research). Software can be customized for automatic anthro measures (for a cost).

Disadvantage:

Relatively Expensive, software does not have automated anthro measures

Manufacturers: 3dMD

Website: http://www.3dmd.com/index.html

Brochure? Yes

5.1.4.5 Cyberware

Cyberware

Cyberware's Head & Face Color 3D Scanner is designed to offer maximum coverage scanning of the human head and face. The system is designed for applications that will benefit from increased scan coverage of the top of the head and under cut areas of the chin. Projects which require high quality data from the eye and mouth area will also benefit from the fine sample pitch of the new Head & Face Color 3D Scanner.

Cyberware's Whole Body Color 3D Scanner takes hundreds of thousands of measurements of the human body in 17 seconds. Four scanheads collect high-speed 3D measurements every 2 mm from head to toe to create an accurate 3D data set. The scanning process captures an array of digitized points, with each point represented by X, Y, and Z coordinates for shape and 24-bit RGB values for color. Color sampling pitch is user selectable at either one or four texels per vertex. The system transfers this data via a USB interface to your computer for immediate viewing.

Specifications

- Four scanheads at optimum angles capture complex contours
- Less than 20-second scan time
- Product design life cycle is over 1,000,000 scans
- Speed 60,000 points per second, digitized to X, Y, Z and R, G, and B components.
- Density 70 points per square centimeter.
- Width 261cm (103")
- Height 290cm (114")
- Depth 235cm (93")
- Weight 300Kg (661 lbs)
- Horizontal
- Environment Subject illumination must be a minimum of 200lx for RGB data collection. Room illumination to 2klx for better quality.
- Cyberware scanners are designed to operate in a typical office environment; 17°C - 25°C (63°F - 77°F), non-condensing. The minimum and maximum temperature ranges are 13°C - 29°C (55°F - 85°F), non-condensing. There is a possibility of data degradation at the limits of temperature tolerance

File Formats: Echo, CyScan, Ply, 3D Studio, OBJ, STL, ASCII, DXF, IGES, VRML, Inventor

Cost: Head and Face: $63,000 to 77,000 Whole Body: $200,000 to $240,000
Advantages: Four scanheads are at optimum angles to capture complex contours (especially for faces), improved coverage greatly reduces post production editing, software can be customized to automatically provide anthro measures.
Disadvantage: Relatively Expensive, long scan time (not as precise as 3dMD)
Manufacturers: Cyberware Website: http://www.cyberware.com/ Brochure? No

5.1.5 Anthropometry: Clothed

Tool	Summary Description	Pros	Cons
Clothed Anthropometry using traditional and 3D Scanning	Traditional anthropometry can be used to ascertain girth, width, and depth measurements; 3D scanning can be used to ascertain bulk and spatial volumes.	Provides the impact of clothing on design of workspaces	Difficult to accurately and repeatedly measure

5.1.6 Data Acquisition: Force

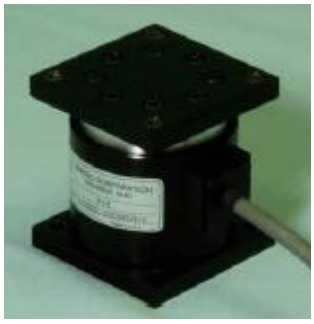
5.1.6.1 Multi-Component Force Sensors

Multi-component force sensors measure the force components in the three principal axes (X, Y, Z) as well as the moment corresponding to each of those axes. These sensors are ideal for research and testing environments as they provide high stiffness, high sensitivity, low crosstalk, excellent repeatability, and proven long-term stability. Applications can range from real-time human performance feedback to multi-axis work efficiency to clinical strength evaluations. They provide

six separate channels of analog input. Typically have bolt-ready top and bottom surfaces for mounting of handles, grips, or other force application interfaces.

AMTI FS-6

AMTI MC3A

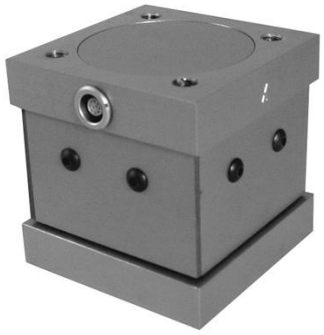


Bertec PY6

Various applications available with both tri-axial force and moment analog signals. Small transducers are best used in laboratory or clinical setting with human force applications due to relatively low force application capacities.
Amplifier: typically require an external amplifier
Size: range from small (1" diameter) force cylinders to intermediate (3") force cubes to larger (>6") force platforms. Platforms allow for high load conditions in materials testing, whereas cubes and cylinders are more appropriate for point load applications.
Applied Force Capacity: ranges from 50 lb. to 1000 lb. for small transducers and greater than 4000 lb. for force platforms.
Light weight, compact design.
Low crosstalk (<2%), hysteresis (±0.2% full scale), and non-linearity (±0.2% full scale) on all channels.
Top Rated Products: AMTI FS-6 (www.amti.biz), AMTI MC3A (www.amti.biz), Bertec PY6 (www.bertec.com)
Price: $7200 (PY6)
Brochure: Yes - PDF

5.1.6.2 Tri-Axial Force Sensors

Tri-axial force sensors offer concurrent measurement of an applied load in the three principal axes (X, Y, Z). These sensors are ideal for measurement of unidirectional force application and evaluation of off-axis force contributions. These sensors do measure real-time sensor point moments. These sensors work well for evaluation of occupational tasks and determining required force input. Typically have bolt-ready top and bottom surfaces for mounting of handles, grips, or other force application interfaces.



Futek MTA400

Futek MTA 600

Various applications available, however best used in unidirectional laboratory or clinical human force applications. Less abundant than multi-component force transducers due to lack of analog moment data output.
Amplifier: typically require an external amplifier
Size: range from small (1" diameter) force cylinders to intermediate (3") force cubes to larger (>6") force platforms. Platforms allow for high load conditions in materials testing, whereas cubes and cylinders are more appropriate for point load applications.
Applied Force Capacity: ranges from 505 lb. to 5000 lb.
Light weight, compact design.
Low crosstalk (<2%), hysteresis (±0.2% full scale), and non-linearity (±0.2% full scale) on all channels.
Top Rated Products: Futek MTA400, Futek MTA600 (www.futek.com)
Price: approximately 3600 CAD
Brochure: Yes - PDF

5.1.6.3 Uni-Axial Force Sensors

Single-component or uni-axial force measurement devices are used to record an applied force in one direction, typically tensile/compressive force. These economical force gauges are ideal for applications where users are interested in basic peak force measurements. They require no external hardware and are battery powered, allowing for easy mobile or on-site use. They can be used to measure required force, determine acceptable and safe work limits, and evaluate fatigue and endurance. Such devices are available with the load application point integrated into the display unit as well as with an external load cell.

Chatillon DFX Series Force Gauge

Chatillon DFS-R Series Force Gauge

Primarily used for basic peak linear (tension/compression) force measurement.
Chatillon (*Largo, Florida, USA*) is the leading supplier of linear force measurement systems.
Force Application Capacity: ranges from 1000 N to 5000 N.
Measurement Accuracy: better than 0.5% full scale (internal load cell), better than 0.1% full scale (external load cell).
Battery powered, not other external hardware required. Over 120 hours of continuous use.
Various attachment accessories available.
Large, easy to read, high-resolution dot matrix LCD display. Units are displayed in oz-f, g-f, lb-f, kg-f, or N.
Equipped with carrying case, external power source, and load cell adapters.
Price: $556 (DFX), $1560 (DFS-R)
Brochure: Yes – PDF *Website*: http://www.chatillon.com/Our%20Products/Chatillon%20Force%20Gauge/forcegauge_intro.html

5.1.7 Data Acquisition: Torque

5.1.7.1 Kistler Instrument Corp. (Amherst, New York, USA)

The Kistler line of torque dynamometers allow for real-time measurement of uni-directional torque. These can be used for various applications including mechanical testing of torque wrenches, torsion testing of springs, ergonomic measurements, and testing of screw connections. The sensor contains a set of shear sensitive quartz discs that response to torsional loads applied about the axis for the device. These sensors can only record torque applied about the axis of the device (Mz).

Kistler 9275 Force Dynamometer

Mounting Plate: flat, rigid plates for mounting onto force application surface, or mounting of handle, tested material or other user interface to the device.
Size (diameter x height): 100mm x 70mm
Measurement Capacity: 200 N.m (1775 in-lb)
Amplifier: external amplifier required.
Moderate crosstalk (<0.1%), hysteresis (±1% full scale), and non-linearity (±1% full scale).
Price: $5300
Brochure: Yes – PDF *Website*: www.kistler.com

5.1.7.2 Futek Advanced Sensor Technology (Thornhill, Ontario, Canada)

The TFF600 Reaction Torque Sensor is primary used for materials testing applications including automotive braking, engine and transmission dynamometers, torque table, fastener testing, aircraft engine testing, and marine shaft torque measurements with shaft horsepower monitors. This device is capable of recording applied load about the axis of the device only. The TFF600 is available in both, aluminum and stainless steel construction and offers a unique solution for torque auditing applications. This device can be used to evaluate low-torque components and controls. Flange-reaction torque sensors measure small-reaction torque levels using flange-to-flange connections in-line with the component under test. This device is designed with flanges, enabling easy installation or adaptation; it is rugged enough for factory use, yet accurate enough for the laboratory.

Futek TFF600

Mounting Plate: flat, rigid plates for mounting onto force application surface, or mounting of handle, tested material or other user interface to the device.
Size (diameter x height): 4.46” x 3”
Measurement Capacity: 115 N.m (1000 in-lb)
Amplifier: external amplifier required.
Low hysteresis (±0.2% full scale), and non-linearity (±0.2% full scale).
Price: 1250 CAD
Brochure: Yes – PDF *Website*: www.futek.com

5.1.7.3 Chatillon (Largo, Florida, USA)

The Chatillon STS Series Torque Sensors are used exclusively with Chatillon DFS-R-ND Series digital gauges. These high accuracy sensors feature "smart technology" that is recognized by the force gauge. The gauge can determine the sensor capacity, scaling requirements and determine sensor status including overload history. These sensors are capable of measuring uni-axial torque about the long axis of the connector. Torque may be measured in oz-in, lb-in, N-cm, kg-cm and N-m in either clockwise or counter clockwise direction. Sensor features a Jacobs chuck type connection for holding samples.

Chatillon STS Series Torque Sensor

Full bridge strain gauge sensors with a 15-pin plug and retractable cord that extends nearly 9ft.
Measurement Capacity: between 0.35 N.m (3 in-lb) and 20 N.m (200 in-lb) depending on model.

Low hysteresis (±0.1% full scale) and non-linearity (±0.1% full scale).
Used with Chatillon DFS-R-ND Series digital force gauge. Torque sensor is a compatible accessory.
Size (diameter x length): 1.2” x 6.0”
Price: $1210
Brochure: Yes – PDF *Website*: www.chattillon.com

5.1.8 Data Acquisition: Grip Force

5.1.8.1 Analog Hand Grip Dynamometer

Analog hand grip dynamometers allow for quantitative assessment of hand grip strength. They use a hydraulic system to measure compression force applied. These sensors do not move or compress when force is applied, thus providing a static, isometric grip force measurement. Force is actively displayed on an analog dial gauge, with units typically displayed in pounds (lb) or kilograms (kg). These tools can be used in a clinical setting to evaluate patient hand function compared to normative data, in a research setting to investigate grip changes a capabilities in various tasks, and in an occupational setting to assess either the capability of a worker to perform a grip-based task/job or determine the required grip force to perform a given job. Hand grip dynamometers evaluate functional strength of the entire upper limb, and do not assess muscular capability of individual muscles. Recommended manufacturers of analog hand grip dynamometers are: Jamar, Baseline.

Analog Hand Grip Dynamometer

Hydraulic compression measurement system
Measurement Capacity: 90-150 kg (200-300 lb)
Power Supply: Mechanical, no power required.

Price: approximately $300

5.1.8.2 Digital Hand Grip Dynamometer

Digital hand grip dynamometers offer measurement of quantitative hand grip strength similar to analog models. The same hydraulic compression system is used, however force values are displayed on an LCD digital gauge. The digital gauge provides a more accurate measurement of maximum achieved force, but does not allow the user to view changes in force level that do not exceed the maximum value (only maximum value is actively displayed). Some manufacturers can calculate average and standard deviation of testing interval. Recommended manufacturers of digital hand grip dynamometers are: Jamar, Baseline.

Digital Hand Grip Dynamometer

Hydraulic compression measurement system
Measurement Capacity: 90-150 kg (200-300 lb)
Power Supply: Battery
Price: approximately $350

5.1.8.3 Integrated Hand Grip Dynamometer

An integrated hand grip dynamometer by Noraxon is specifically designed for grip force measurement with a Noraxon EMG collection system. This device plugs into any of the Noraxon EMG systems and acts just as an additional EMG channel to measure time-varying, recordable grip force. This sensor requires no additional calibration or setup, as it is fully compatible with the EMG systems. Like stand-alone analog and digital dynamometers this device provides static, isometric whole hand grip force measurement for various applications, but also has a platform for pinch grip measurement and can provide biofeedback readings. Due to system requirements, clinical and laboratory setting are the most realistic usage environments.

Noraxon Integrated Hand Grip Dynamometer

Capabilities: hand grip force, pinch grip force, biofeedback
External Requirements: Noraxon EMG system (compatible with all models)
Measurement Capacity: 600 N (135 ft-lb)
Solid and durable construction
Cost: $600 to $3000 (depending on force range) plus $9500 for data collection system and software
Brochure: Yes – PDF *Website*: www.noraxon.com

5.1.9 Data Acquisition: Goniometers/Torsiometers

The comprehensive range of Biometrics' goniometers and torsiometers (Ladysmith, VA, USA, http://www.biometricsltd.com/index.htm) are ideal for quick, simple, and accurate measurement of joint movement in multiple planes and are the industry leader for this type of instrumentation. Extremely robust, lightweight and flexible, the sensors can be comfortably worn undetected under clothing, without hindering the actual movement of the joint. Specifications for all Biometrics Goniometers and Torsiometers:

Transducer type: strain gauge
Life: 600,000 cycles typical
Accuracy: ±2° measured over a range of ±90°
Repeatability: ±1° measured over a range of 90°
Operating temperature range: +10°C to +40°C
Temperature zero drift: < or = 0.15 degrees angle/°C

5.1.9.1 Single-Axis Goniometers

Biometrics' goniometer F35 measures angles in one plane only. This smallest goniometer is designed to measure flexion/extension of finger and toe joints. These are strain gauge sensors that stream real-time angles to an external data acquisition unit. Biometrics' sensors are sold separately or as part of complete measurement systems. Available systems include instrumentation for static angle readout, dynamic on line data acquisition in 2, 4 or 8 channel configurations, or fully portable data collection.

Biometrics Single-Axis Goniometer

Brochure: No
Price: Approximately $680

5.1.9.2 Twin-Axis Goniometers

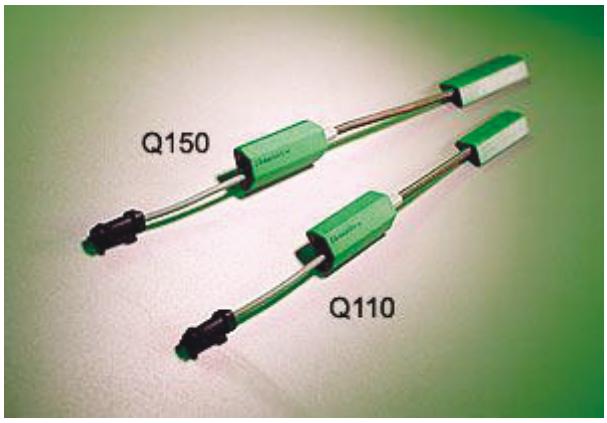
The "SG" series twin axis goniometers simultaneously measure angles in up to two planes of movement. For example, to measure wrist movements, the endblocks of the SG65 or SG75 goniometer are attached on the dorsal surface using double sided tape, one end over the third metacarpal, the other over the midline of the forearm, with the wrist in the neutral position. The goniometer has two separate output connectors, one is measuring flexion/extension, the other radial/ulnar deviation. When used to measure a single axis joint such as the knee or elbow, or when measuring a single plane of a twin axis joint, simply connect one channel, the other remains redundant. All twin axis SG series goniometers function the same way, the difference being physical size.

Biometrics SG Series Twin Axis Goniometers

Brochure: No
Price: Approximately $810

5.1.9.3 Single-Axis Torsiometers

Biometrics' "Q" series single axis Torsiometers are designed for measurement of rotations in one plane, e.g. forearm pronation/supination or neck axial rotation. If the Torsiometer is bent in planes X-X or Y-Y the output remains constant. All Torsiometers function in the same way, the difference being physical size.



Biometrics Single-Axis Torsiometer

Brochure: No
Price: Approximately $680

5.1.10 EMG

5.1.10.1 Motion Lab Systems (Baton Rouge, LA, USA)

Motion Lab Systems (Baton Rouge, LA, USA) offers a large range of high performance, multi-channel EMG systems for both clinical and research use. Systems (MA300) are fully customizable and range from 6 to 18 EMG channel systems. The 10-1000Hz input channels can be used for variable input types including EMG, EKG, goniometers, event switches and pressure sensors. Highlighted features include MS-905 Basic EMG Graphing Software, gain calibration, signal level indicators, subject belt, and additional ground electrode. This EMG system contains all system hardware in a single subject backpack unit. A radio telemetry unit can be added to this system to create a telemetric EMG system with no additional modifications or add-ons. Typical system characteristics and specifications are listed below.

Motion Lab Systems MA300-XII EMG System

Maximum EMG Bandwidth: 10-1000 Hz
Variable Low Pass EMG Filter: 1000 Hz
Input Impedance: > 100 MΩ
Common Mode Rejection Ratio (CMRR): 10 dB @ 40 Hz
Output Voltage: ± 5 V
Customizability: 8 and 16 channel versions, telemetric add-on
Price: $13,000 to $40,000 depending on number of channels and capabilities
Brochure: No *Website*: http://www.motion-labs.com/prod_emg_systems.html

5.1.10.2 Delsys (Boston, MA, USA)

The Delsys Bagnoli line of desktop EMG systems offer consistent and easy-to-use EMG hardware that can be used from novice and biofeedback purposes to advanced research science. The system itself is low-profile and compact in design. These systems are available in 4, 8, and 16-channel models. All systems feature a 50/60Hz line interference check, amplifier saturation check, LED indicators, audio indicators. These systems have good integration into an existing data acquisition system, as they have BNC outputs, analog isolated channels, an integrated A/D connector, and start/stop triggering feature. All systems are equipped with Delsys patented parallel bar sensors rather than standard clip or snap electrodes. Systems can also accept various other biofeedback indicators such as goniometers, force sensors, switches, and ECG sensors.

Delsys Bagnoli Desktop EMG System

Maximum EMG Bandwidth: 20-450 Hz ±10%
Input Impedance: $>10^{15}\Omega$ //0.2pF
Common Mode Rejection Ratio (CMRR): 92 dB (typical)
Output Voltage: ± 4.8V
Customizability: 4, 8 and 16 channel versions, wireless options
Price: $6500 (4 channel, tethered system) to $30,000 (16 channel, wireless)
Brochure: Yes – PDF *Website*: http://www.delsys.com/

5.1.10.3 Noraxon (Scottsdale, AZ, USA)

Noraxon offers fixed cable EMG systems, but specializes in wire-free telemetric systems. The TeleMyo 2400T G2 Transmitter and Receiver create an excellent balance between surface and fine-wire telemetric EMG technology that sends real-time EMG and other analog signals up to 300 feet (100 meters) by wireless transmission to a desktop computer or notebook. This system combines high-quality, scientifically reliable data with mobility, flexibility and ease-of-use for clinicians, researchers, sports medicine professionals, ergonomists and athletic trainers. The default system includes a 4, 8, 12 or 16 channel transmitter unit, a USB based PC-interface receiver box, active pre-amplified leads, battery charger, and a belt clip and pouch for easy use. The default system comes fully equipped with four, eight, twelve, or sixteen active EMG leads. An additional transmitter can be added to the system for up to 32 analog input channels.

Noraxon Telemyo 2400T G2 Telemetric EMG System

Maximum EMG Bandwidth: 10-1000Hz

Input Channel Analog Band Pass Filter: 10-500 Hz
Input Impedance: > 100 MΩ
Common Mode Rejection Ratio (CMRR): >100 dB
Output Voltage: ± 5 V
Customizability: 4,8,12, and 16 channel units, additional transmitter for up to 32 channels
Price: $19,000 to $29,000 depending on number of channels
Brochure: Yes – PDF *Website*: http://www.noraxon.com/

5.1.10.4 Twente Medical Systems International (Netherlands)

The Porti system from Twente Medical Systems (TMS) is a multi-channel ambulatory and stationary system for physiological research. The Porti can have unipolar electrophysiological inputs (ExG), bipolar electro-physiological inputs (BIP) and auxiliary inputs (AUX). The Porti system can be equipped having different number of input channels. Porti's with 8, 16, 24 and 32 channels are available. Each of these channels has a +5V and -5V output in order to use active sensors or sensor modules. The Porti can be used for both stationary as well as ambulatory measurements. In stationary setup an external power supply, which plugs into the mains socket, powers the Porti. The Porti is connected to a PC by means of a bi-directional glass fiber. It is also possible to use the built-in BlueTooth telemetry to send the data directly to a PC.

TMSI Porti System

Hardware Filtering: None
Input Impedance: > 10^{12} Ω
Common Mode Rejection Ratio (CMRR): > 100 dB

Output Voltage: ± 5 V
Customizability: 8, 16, 24, and 32 channel versions
Price: $11,000 to 17,000 depending on number of channels
Brochure: No *Website*: http://www.tmsi.com/?id=12

5.1.11 Force Plates

While force plate technology does not differ greatly across models and providers, plate size, force capacity, and mounting solutions are the primary choice criteria.

5.1.11.1 AMTI-Advanced Medical Technology, Inc (Watertown, MA, USA)

As with their other force sensors, AMTI offers a wide range of force plates with varying capabilities and capacities. The OR6 series of force plates allows for dynamic usage and is ideal for a range of applications. These 6-DOF strain gauge force plates feature composite construction that allows a low-mass device with a high resonant frequency. These force plates have a 18.25” x 20” surface, and are available in 1000-lb, 2000-lb and 4000-lb capacities. The force plates require use of an external amplifier and data collection software.

AMTI OR6-6-1000 Force Plate

Size (WxLxH): 18.25” x 20” x 4”
Weight: 40 lb
Hysteresis: ±0.2% FSO
Sensor Type: Strain gauge bridge
Number of Channels: 6 (Fx,Fy,Fz,Mx,My,Mz)
Cross-talk: < 2% on all channels
Non-linearity: ±0.2% FSO
Capacity: 1000-lb, 2000-lb, 4000-lb
Price: Approx. $10K

Brochure: Yes – PDF *Website*: www.amti.biz

5.1.11.2 Bertec Corporation (Columbus, OH, USA)

The Bertec 4060 series offers force plates that work well in a variety of clinical and research gait analysis applications. Each force plate consists of precision-engineered, strain gauged load transducers that precisely measure six components: three orthogonal forces and the moments about each axis. Each plate contains a built-in, 16-bit digital gain amplifier and signal conditioning unit, which make the use of calibration matrices obsolete. The 4060-07 model comes with a lightweight aluminum top that will withstand years of use. It is available in two standard load ranges (5,000 N or 10,000 N) and custom load ranges. State-of-the-art electronic design internally corrects for cross-talk, so the output is a true reading.

Bertec FP4060-07-1000 Force Plate

Size (WxLxH): 15.75” x 23.62” x 2.95”
Weight: 84 lb
Sensor Type: Strain gauge bridge
Number of Channels: 6 (Fx,Fy,Fz,Mx,My,Mz)
Cross-talk: internal correction, negligible
Non-linearity: ±0.2% FSO
Capacity: 1100-lb, 2200-lb
Price: Approx. $10K
Brochure: Yes – PDF *Website*: www.bertec.com

5.1.11.3 Kistler Instrument Corp. (Amherst, New York, USA)

The Kistler 9253B series multi-component force plates consist of four force measuring elements. Each element contains a preloaded force sensor. The force sensor contains quartz rings which are mounted between two steel plates in the housing of the sensor. Two quartz rings are sensitive to shear and measure the force components Fx and Fy, while a quartz ring sensitive to pressure

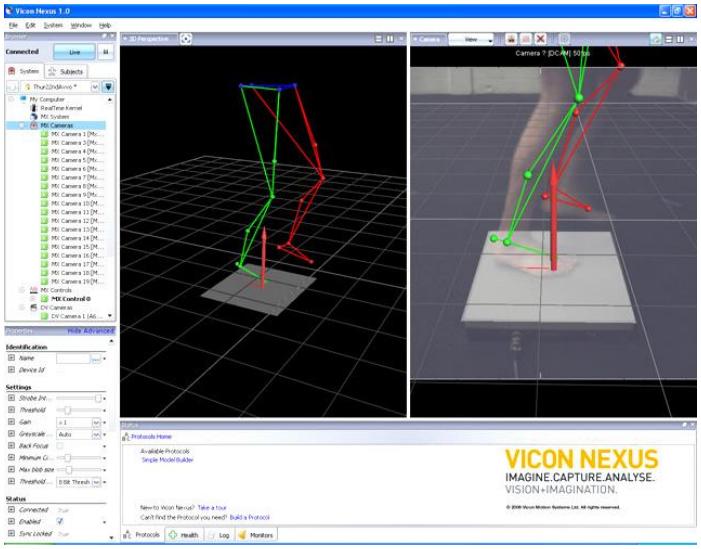
measures the component Fz of a force acting in any direction on the force plate. The electrical charges proportional to the different components are led via electrodes to the connector contacts. These plates are offered in 20 kN, 25kN, and 30kN versions. While the 3 moment components Mx, My, Mz are not recorded directly, they can be calculated.

Kistler 9253B Multi-Component Force Plate

	B11/12	B21/22	B23
Size (WxLxH)	40.0cm x 60.0cm x 10.0cm		
Weight (kg)	40	90	85
Sensor Type	Quartz ring		
Number of Channels	3 (Fx,Fy,Fz)		
Cross-talk: ±2 %	±2 %		
Non-linearity	±0.5% FSO		
Capacity(kN)	20	30	25
Price	Approx. $22K-39K		
Brochure: Yes – PDF *Website*: www.kistler.com			

5.1.12 Motion Capture Systems

5.1.12.1 Passive Optical - Vicon



Vicon Motion Systems

Passive optical motion tracking systems use retroreflective markers to reflect back infrared light generated at the camera lens. Camera thresholds are adjusted to ignore skin and fabric, but reflect the 3D location of markers typically placed at boney landmarks or other points of interest. The centroid of the marker is estimated as a position within the 2 dimensional image that is captured. The grayscale value of each pixel can be used to provide sub-pixel accuracy by finding the centroid of the marker. An object with markers attached at known positions is used to calibrate the cameras and obtain their positions and the lens distortion of each camera is measured. Providing two calibrated cameras see a marker, a 3-dimensional fix can be obtained. Though these systems are fully expandable to use hundreds of cameras in advanced CGI applications, biomechanical evaluation systems typically consist of 6 to 24 cameras. Collection software is typically native to the manufacturer of the system.

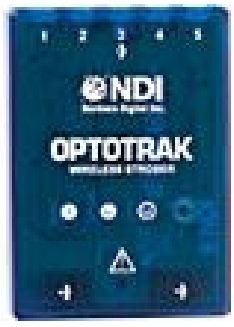
- 1 Campbell 20 (54 cm) wide sliding caliper
- 1 Campbell 10 (18 cm) small bone caliper
- 1 Segmometer 4
- 1 Head square with tape
- 2 Slim Guide Skinfold Calipers
- 2 Steel anthropometric tapes
- 1 Anthropometric Devices Fundamentals CD
- 1 Cordura carrying case - LWH 70 x 35 x 10 cm 3.5 kg

Starting at approximately $25K per camera plus software and accessories.

Advantages: Passive systems do not require the user to wear wires or electronic equipment as the markers are attached directly to the skin. These systems can generate continuous motion data streams and allow rapid visualization and input for kinematic models. These systems can be custom-integrated, acquiring and exchanging data with third-party devices including external capture technologies like force plates, data gloves, and eye trackers as well as HD compliant time code, genlock, EMG and any other digital device.

Disadvantage: cost, required expertise and marker switching/dropout
Manufacturers: Vicon Website: http://www.vicon.com/ Brochure? User Guide in .pdf

5.1.12.2 Active Optical - Optotrak



Optotrak Certus Active optical motion capture systems triangulate positions by illuminating one LED at a time very quickly or multiple LEDs with software to identify them by their relative positions. Rather than reflecting light back that is generated externally, the markers themselves are powered to emit their own light. The active aspect of these systems drastically reduces the problem of marker switching as each marker LED has a unique identification. As with passive systems, active systems can generate continuous motion data streams and allow rapid visualization and input for kinematic models. These systems provide extremely precise boney landmark and segment cluster motion tracking for static or moderately dynamic clinical and experimental biomechanics research. Because the active LED markers require a power supply to emit an infrared signal, active markers require cables that may limit dynamic participant movements.
Approximately $40K per camera bank (3 cameras), with NDI First Principles collection software, plus accessories.
Advantages: These systems offer maximum flexibility and expandability for motion capture applications through its unsurpassed accuracy, high-speed marker frequency, portable design, and virtually wireless marker option. Built with the superior accuracy and reliability of the renowned Optotrak 3020 series, Optotrak Certus is the gold standard among research scientists. New systems are backwards compatible with old Optotrak camera banks, and a maximum marker frequency of 4600 Hz enables data capture high speeds. These systems start at Like passive systems, active systems can be custom-integrated, acquiring and

exchanging data with third-party devices including external capture technologies like force plates, EMG, data gloves, accelerometers, and digital video.
Disadvantage: cost, required expertise and marker switching/dropout
Manufacturers: Northern Digital Inc Website: http://www.ndigital.com Brochure? No, user guide in .pdf

5.1.12.3 Electromagnetic - Fastrak

Fastrak Electromagnetic systems calculate position and orientation by the relative magnetic flux of three orthogonal coils on both the transmitter and each receiver. The relative intensity of the voltage or current of the three coils allows these systems to calculate both range and orientation by meticulously mapping the tracking volume. The sensor output is 6DOF, which provides useful results obtained with two-thirds the number of markers required in optical systems, eg. one on upper arm and one on lower arm for elbow position and angle. The markers are not occluded by nonmetallic objects but are susceptible to magnetic and electrical interference from metal objects in the environment, like rebar (steel reinforcing bars in concrete) or wiring, which affect the magnetic field, and electrical sources such as monitors, lights, cables and computers. The sensor response is nonlinear, especially toward edges of the capture area. The wiring from the sensors tends to preclude extreme performance movements. The capture volumes for magnetic systems are dramatically smaller than they are for optical systems. With the magnetic systems, there is a distinction between "AC" and "DC" systems: one uses square pulses, the other uses sine wave pulse.
Typical systems are approximately $60K.
Advantages: These systems offer maximum flexibility and expandability for motion capture applications through its unsurpassed accuracy, high-speed marker frequency, portable design, and virtually wireless marker option. Built with the superior accuracy and reliability of the renowned Optotrak 3020 series, Optotrak Certus is the gold standard among research scientists. New systems are backwards compatible with old Optotrak camera banks, and a maximum marker frequency of 4600 Hz enables data capture high speeds. These systems start at Like passive systems, active systems can be custom-integrated, acquiring and

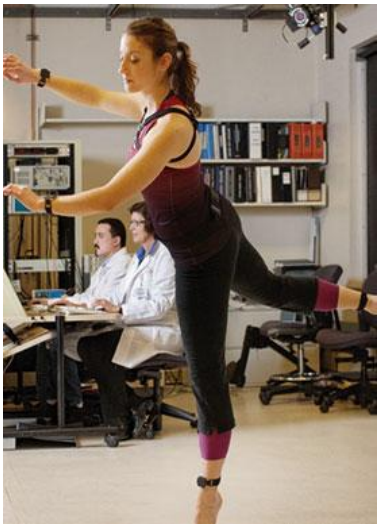
exchanging data with third-party devices including external capture technologies like force plates, EMG, data gloves, accelerometers, and digital video.
Disadvantage: These systems can only have a small number of markers, are relatively expensive, are tethered to a power supply, and can be distorted by electromagnetic fields. They have known negative EMG interactions and require extensive calibration.
Manufacturers: Polhemus Website: http://www.polhemus.com/?page=Motion_Fastrak Brochure? Yes

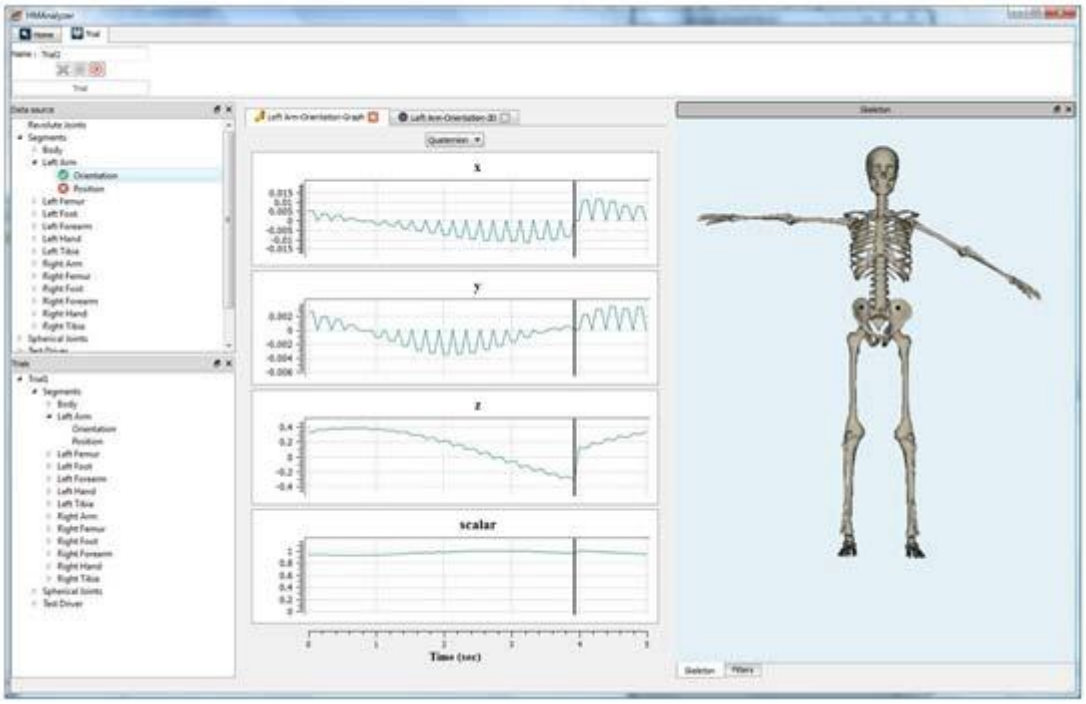
5.1.12.4 Xsens Inertial Motion Tracking Systems

Xsens MVN Wireless Inertial Motion Capture Suit Inertial Motion Capture technology is based on miniature inertial sensors, biomechanical models and sensor fusion algorithms. The motion data of the inertial sensors (inertial guidance system) is often transmitted wirelessly to a computer, where the motion is recorded

or viewed. Most inertial systems use gyroscopes to measure rotational rates. These rotations are translated to a skeleton in the software. Much like optical markers, the more gyros the more natural the data. No external cameras, emitters or markers are needed for relative motions. Inertial mocap systems capture the full six degrees of freedom body motion of a human in real-time. Modern inertial systems are typically in the form of a full body suit with and inertial sensor at each body segment
$90,000 (includes software, support, 1 day of training)
Advantages: These systems offer maximum flexibility and expandability for motion capture applications through its unsurpassed accuracy, high-speed marker frequency, portable design, and virtually wireless marker option. Built with the superior accuracy and reliability of the renowned Optotrak 3020 series, Optotrak Certus is the gold standard among research scientists. New systems are backwards compatible with old Optotrak camera banks, and a maximum marker frequency of 4600 Hz enables data capture high speeds. These systems start at Like passive systems, active systems can be custom-integrated, acquiring and exchanging data with third-party devices including external capture technologies like force plates, EMG, data gloves, accelerometers, and digital video.
Advantage over camera systems: 6 DOF system with occlusion-free, real-time visualization, and minimal fine-tuning, filtering or post-processing. Very easy setup, resulting in a fast pipeline relative to optical systems. No solving, no occlusion, portability, and large capture areas. Advantages over I2M: Wireless, has position information (i.e. from an origin, the ground etc.)
Disadvantages from camera systems: lower positional accuracy and positional drift which can compound over time. Disadvantages from I2M: More expensive
Manufacturers: Xsens MVN Wireless Inertial Motion Capture Suit Website: http://www.xsens.com/en/general/mvn Brochure? Yes

5.1.12.5 I2M Inertial Motion Tracking System with HM Analyzer





Our I2M (IMUs to Motion) family of products provide an unmatched choice of sensors, features and expandability. All our sensors while smaller than a typical wristwatch contain 8GB of memory. All sensors allow the customer to change the settings to either 2g or 6g depending on their needs without having to purchase multiple sensors. Our SXT series allow up to 32 motion trackers to be used either individually or together with all sensors being synchronized

SXT: These full featured IMUs can be used for either continuous monitoring of synchronized devices or in applications that require real-time streaming to a computer. The SXTs use a proprietary low-power wireless communications protocol to Wireless Access Control Units (WCTL) that are connected to the computer by USB. The SXTs and WCTLs both have large data buffers to ensure that data is never dropped, even if communications are temporarily interrupted or if the SXTs are temporarily out of range of the WCTLs.

Property	Accelerometer	Gyroscope	Magnetometer
Axes	3	3	3
Range	±2 g/±6 g	±1500°/s	±6 Gauss
Noise Density	128 µg/√Hz	z: 0.126°/s/√Hzx, y: 0.070°/s/√Hz	4 mGauss/√Hz
Bandwidth	50 Hz	50 Hz	50 Hz
Sample Rate	128 Hz	128 Hz	128 Hz
Resolution	14 bits	14 bits	14 bits

Device Properties	
Wireless streaming range (SXT only)	10 m
Buffered streaming (SXT only)	<0.5 ms
Streaming battery life (SXT only)	>8 h
Logging battery life	>16 h
Dimensions	48.5 x 36 x 12 mm
Weight	<22 g
Materials	6061 clear anodized aluminum, ABS plastic, and Velcro straps
Calibration	Pre-calibrated across full temperature range. No field calibration required.
Data transfer	High speed USB 2.0 (480 Mbps)
Data format	Documented binary format and/or plain text (CSV)
Application development	Complete cross-platform software development kit included for Windows, Mac, and Linux. Compatible with MATLAB™, Java, Python and C.

HM-Analyzer captures motion orientation data real-time for up to 18 Sensors. The user can map I2M SXT sensors to selected joint segments such as trunk, pelvis, arms, etc

The software takes care of joint definitions and conversions. The user simply needs to identify the joint that is mapped to the specified sensor.

The application synchronizes the data automatically. So all you need to do is put the physical sensors in place, tell the application where the sensors are located on the body, perform the calibration sequence and record. The user can then perform various analysis within HM-Analyzer or export data.

The calibration sequence consists of asking the user to adopt a specific posture (which matches the application's posture) and click calibrate.

- Capture motion orientation information from SXT sensors
- Map segments or joints of a 3D model skeleton to motion capture sources
- Dynamically display axes of orientation of mapped segments or joints
- Dynamically display Euler or Quaternion orientation data as a scrolling, 2D graph
- Record multiple trials of data
- Display recorded trial information as a static, 2D graph
- Apply filters (APDF, Butterworth, Differentiation, Rectification) to recorded trial data
- Export motion data (Euler or Quaternian) to CSV (comma separated value) format
- Acceleration data

$37,500 (includes 16 SXT IMU kit, HM Analyzer software)
Advantage over camera systems: 6 DOF system, no occlusion, portability, outdoor capable, and large capture areas. Advantages over XSens: Less costly, can be custom programmed by NexGen for our needs.
Disadvantages from camera systems: lower positional accuracy and positional drift which can compound over time. Disadvantages from Xsens: No positional information, logger (not wireless), less number of body segments.
Manufacturers: NexGen Ergonomics Website: http://www.nexgenergo.com/ergonomics/I2M-IMUs.html http://www.nexgenergo.com/ergonomics/HM-Analyzer.html Brochure? No

5.1.13 Pressure Mapping

5.1.13.1 FSA: Pressure Mats

FSA offers various sizes of pressure mats, such as Hand Sensor Array (HSA) (hand-sized), and Seat and Back mats (larger sized).

The HSA comes in either an 8 x 8 array of 1" sensors or as a 24 x 24 array of 5/16" sensors inside a flexible mat material. The HSA can be used for numerous applications where you grasp, grab or apply a force to a tool, device or object. You can easily see the pattern of force being exerted (via the software's color mapping display) of each finger as an object is grasped.

Similar, to our other mapping products (e.g. seat or back) the system will provide a detailed recording of each sensors PSIU readings over time as well as a real-time display showing each sensors pressure (unless the system is being used in data logging mode). The maximum force that can be measured is 30 psi.

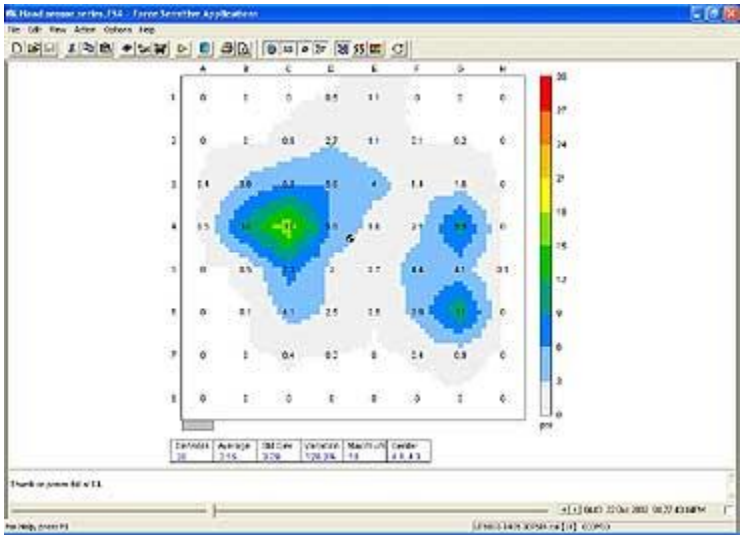
The HSA uses SoftFlex, a new generation of FSA sensing mats that are more durable, flexible and drapable. They feel soft like three layers of fabric and conform easily to soft interface shapes.

The HSA can be added to an existing system or configured with FSA 4D software, Universal System Base, High Pressure Calibration Kit, Manual and Trigger. A telemetry option is available.

Users can also use the OCX control in LabView to set audible alarms when specified PSI levels are exceeded.

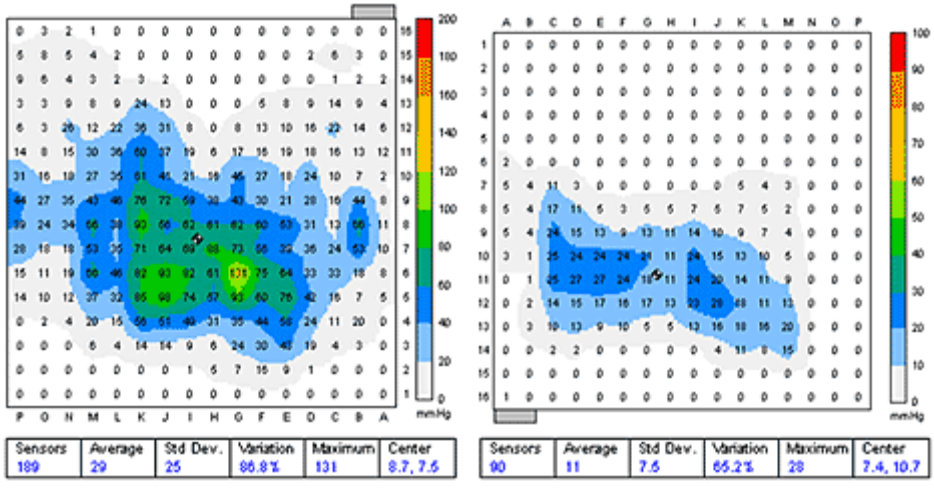
Data gathered can easily be transferred to a spreadsheet to facilitate in depth statistical analysis.

FSA 4D software allows for video synchronization of the captured data with individual video frames for users of Windows XP.



The FSA standard seat and back mats (SPMS) as well as the larger industrial seat and back mats (IPMS) have various applications including validation of product designs or in the research and development of next generation products. A frequent application is in the seating area such as in the automotive sector helping to design more comfortable/supportive seats, or for the development of ergonomically correct office seating.

The FSA system's objective data quickly informs the designer of the impact changes have on the effectiveness of the product achieving design goals. It can shorten the design cycle by helping the design team quickly focus on ideas and materials that match the design goals and demonstrate when they are reached. Data gathered can easily be transferred to a spreadsheet to facilitate in depth statistical analysis. Gather data over time as the study subject is driving or riding with the remote feature.



Seat and back pressures in a pickup truck just after ingress.

Standard Mat
Sensing Area Dimensions:
Seat Mat: 43 cm. x 43 cm. (17" x 17")
Mat Dimensions:
Seat Mat: 53 cm. x 53 cm. (21" x 21")
Other sizes available depending on application.

Industrial Mats:
Sensing Area Dimensions:
Seat Mat: 43 cm. x 43 cm. (20.5" x 21.5")
Back Mat: 51 cm. x 59.7 cm. (21.5" x 23.5")
Mat Dimensions:
Seat Mat: 53 cm. x 53 cm. (27" x 27")
Back Mat: 61 cm. 77.5 cm. (28.5" x 30.5")
Other sizes available depending on application.

Mat Material: Nylon rip stop
Sensor Number and Type: 256 piezo resistive sensors
(1024 available on request)
Sensor Size:
Seat Mat: 24.5 mm. x 24.5 mm. (1" x 1")
Back Mat: 57 mm. 29 mm. (2¼" 1 1/8")
Sensor Arrangement: 16 x 16 array
Mat Thickness: 0.36 mm (0.014")
Sample Rate: 9200 sensors per second (35 Hz)
Calibrated Pressure Range: 0-200 mmHg (0 - 4 psi)
Accuracy: Variation Coefficient* less than 10% at manufacture
Maximum Allowable Force: 1,000 mmHg (0-200 psi)
On Board Remote Scanning: 448 frames of seat mat at various speeds

*Variation Coefficient is the Standard Deviation expressed as a percentage.
Computer Interface:
Dimensions: 4 cm x 14 cm x 15 cm
Weight: 490 g
Input: two 34-pin Insulation Displacement Connector
Output: RJ-45 (8-wire cable) or USB cable

Power Supply:

•9-volt, 500-mAmp AC/DC converter or 9-volt disposable battery •Indicator lights for power, diagnostics and scan rate •Built in trigger for initiating remote reading Additional Hardware: •Manual Trigger (90 cm long RJ-45 momentary contact trigger switch) •Calibration system Optional Extras: •Additional 4 Meg memory for increased storage •Autocalibrator •Wifi communications •Custom mat sizes
Cost: $6650 base system + approx. $2000 for mat
The advantage to FSA pressure mats is a lower fidelity and lower cost than other pressure mats (e.g. Tekscan high speed mats)
Website: http://www.nexgenergo.com/ergonomics/fsaseatback.html http://www.nexgenergo.com/ergonomics/nexhand.html Brochure? No

5.1.13.2 Tekscan: High Speed and High Force Range Pressure Mats

Tekscan offers various sizes and solutions for pressure mats, including systems with higher capabilities for time resolution and high peak forces.

The I-Scan System offers tactile pressure and force measurement capable of measuring up to 20 kHz. High Speed *I-Scan* is an enhanced version of the *I-Scan* pressure and force measurement system, that supports faster sensor scanning speeds (up to 20,000 Hz). The system is ideal for measuring high impact forces, especially during martial arts and crash testing.

Key High-Speed Features: • Fast, accurate, and repeatable measurements • Dynamic recording and playback • Graphing and data analysis capabilities • Real-time pressure displays • Durable & reusable sensors • Sensor scan rates of up to 20,000 Hz (frames per second) • Easy set-up & portable • Static & dynamic pressure measurement • High x-y resolution • Many uses per sensor • Over 75 standard shapes in varying pressure ranges offered, some trimmable • Multiple available pressure ranges up to 30,000+ psi • Real time pressure measurement • Software features include: • View & save multi-frame movie files • Plot force/pressure/area • Peak pressure vs. time • ASCII Output for additional data analysis
Cost: $35K
The advantage to the high speed system is the ability to monitor high-speed events like rifle recoil forces.
Website: http://www.tekscan.com/products Brochure? No

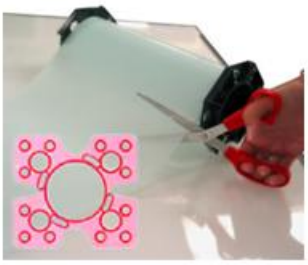
5.1.13.3 Tekscan: Prescale Pressure Measuring Film (Fujifilm)

Prescale™ film is used to measure contact pressures. The film structure consists of micro-encapsulated color forming and developing material. When pressure is applied to the film, a red color impression is formed in varying density according to the amount of pressure and pressure distribution.

Prescale film is used in applications requiring:

- static pressure measurements
- visual pattern of peak pressure

- one-time use



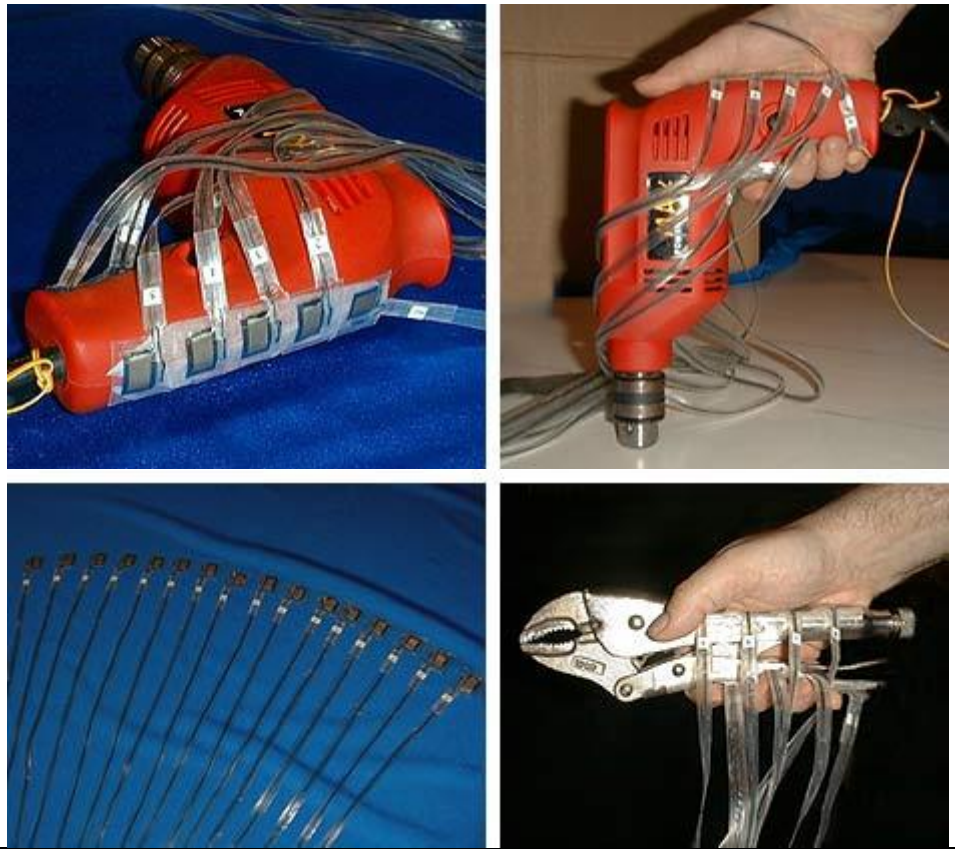
Key High-Speed Features: • Static pressure measurement • High x-y resolution • One-time use • Film is available in rolls and can be cut to size • 7 available pressure ranges up to 30,000+ psi • Peak Pressure Snapshot • Optional Digital Analysis Software includes: • Pressure cross-section & analyzing specific points • Histogram analysis • Total weight distribution on bar graph • ASCII Output for additional data analysis
Cost: $57 per 8.5”x11” sheet
The advantage to the Fujifilm is the relatively very low cost.
Website: http://www.tekscan.com/pressure-indicating-film.html Brochure? No

5.1.13.4 Nexgen: Intelligent Sensor Series

The Intelligent Sensor Series has various options typically in 16 sensor configurations. The Octopus format or configuration consists of 16 individual sensors that can be mounted anywhere. The Strip format/configuration is a series of 16 one-inch sensors.

Similar to our other sensor products, the ISS configurations connect to the computer interface module for real time acquisition or via the computer interface that can gather and store sensing data separate from the computer. (It can be worn by the subject on a nylon web belt.)

Each of the either 8 or 16 individual sensors can be mounted either on a device or the subject to obtain synchronized data from one or more sources (e.g. 2 handed operations). The individual sensors are covered with a Teflon coated laminate which makes them more durable.



Cable Length: Each wire is 20 inches long with all wires gathering to a IDC connector which attaches to a 6 ft. Ribbon cable extension that plugs into the interface module.

Sensor Type: Piezo resistive sensors

Sensor Size: 0.5" X 0.5" X 0.014" (thickness)

Sensor Area: 5/16" X 5/16"

Number of sensors: 8 or 16 per ISS (one per wire)

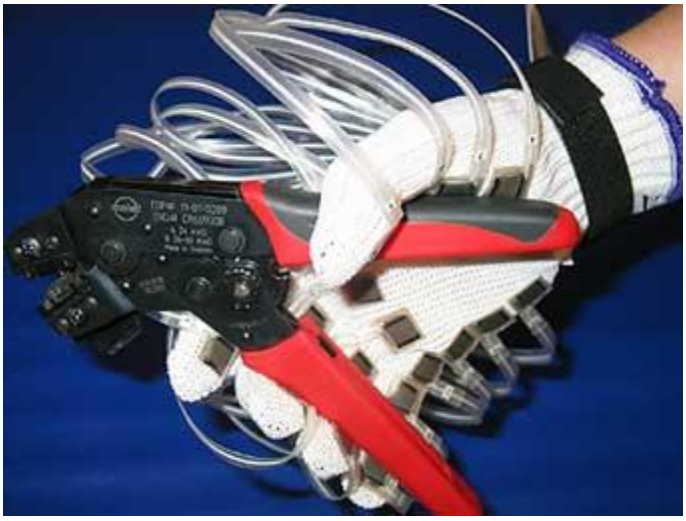
Sample Rate: 3032 sensors per second 12 bit mode, approximately 6064 in 8 bit

mode Calibrated Pressure Range: 0-5000 mmHg (0 - 100 psi) Accuracy: Variation Coefficient less than 10% at manufacture Maximum Allowable Force: 100 psi Warranty: 1 Year Standard, but may vary depending on application
Cost: $6650 base system + approx. $5000 for sensor strip
Website: http://www.nexgenergo.com/ergonomics/nexintel.html Brochure? No

5.1.13.5 Nexgen: Glove Pressure Mapping

The Glove Pressure Mapping System (GPMS) is a multi-sensor hand force data acquisition system that consists of an Ultrathin Glove Mat and a Computer Interface. The GPMS incorporates the ISS sensors in 20 and 24 sensor configurations. The sensor locations can easily be modified by the customer and are mounted using double-sided tapes. The individual sensors are covered with a Teflon coated laminate which makes them more durable.

The GPMS has various ergonomics applications including hand-tool analysis, design and research, as well as clinical applications.



Twenty and twenty-four sensors are used in the standard configurations that results in a sampling rate of over 100 Hz. They are calibrated with a known load in a calibration jig. Variation coefficient (which is the standard deviation expressed as a percentage) is within acceptable quality control range of ± 10%

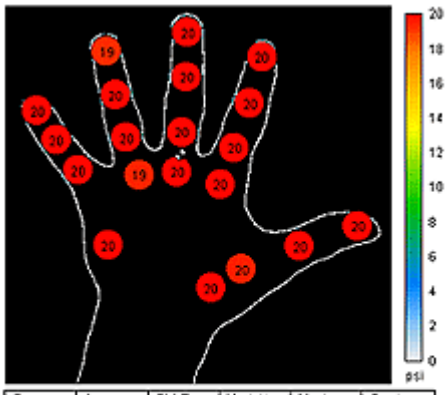
The computer interface is designed to gather and store sensing data separate from the computer. It can be worn by the subject on a nylon web belt.

Menu controls in the software control the speed interval of scanning in Remote Mode, from minutes to hundredths of second (the system can scan at up to 3072 sensors per second). The number of scans stored in the buffer is dependent on the number of sensors. For instance a seat of 256 sensors results in 448 scans stored or 114,688 data points. A glove of 20 sensors could store approximately 5734 scans. For more data collection a 4 Meg memory expansion module is available.

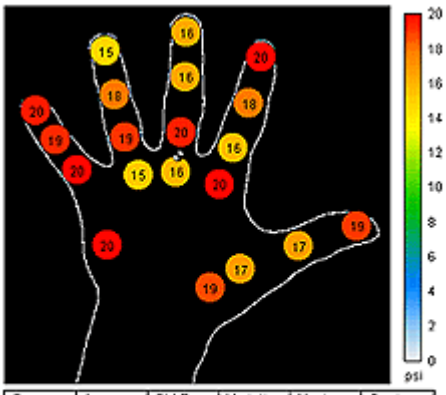
Remote sessions are controlled by a white button at the rear of the computer interface or with a switch that plugs into the RJ45 port, also at the rear. Toggling either switch will start the scanning, which is confirmed by the red led on the front of the interface. You can start and stop as often as you wish during a session. Each start/stop is signified in the download data with a complete red scan as a divider.

Download speed is dependent on the size of the number of scans taken in remote mode but typically is only a few seconds. The serial port connection functions at 115200 baud.

A 9-volt alkaline battery powers the unit in Remote Mode. More power is consumed on data download than while scanning. Also if you plug the AC/DC adapter in before download battery life is preserved.



20 PSI



12 PSI down

Gloves are designed to fit both left and right hands (ambidextrous) and can be ordered in various sizes as shown below:

Standard Glove Size	Ambidextrous Glove Size
6	X-Small
7	Small
8	Medium
9	Large
10	X-Large

Specifications

Mat Material: Fabric sensors mounted on a flexible glove

Sensing Area: 20 or 24 sensors of .25" X .25"

(additional sensors can be added on special order)

Sensor Size: .25" X .25"

Mat Thickness: 0.36 mm (0.014")

Sample Rate: 3072 sensors per second

Calibrated Pressure Range: 0-100 Psi

Accuracy: Variation Coefficient* less than 10%

or approximately ± 10 mmHg

*Variation Coefficient is the Standard Deviation expressed as a percentage.

Computer Interface:

Dimensions: 4 cm x 14 cm x 15 cm

Weight: 490 g

Input: two 34-pin Insulation Displacement Connector

Output: RJ-45 (8-wire cable)

Power Supply:

•9-volt, 500-mAmp AC/DC converter or 9-volt disposable DC battery

•Indicator lights for power, diagnostics and scan rate

•Built in trigger for initiating remote reading

Additional Hardware:

•Manual Trigger

(90 cm long RJ-45 momentary contact trigger switch)

•Calibration system

Optional Extras:

•Additional 4 Meg memory for increased storage on interface during remote scans

•Web belt (holds interface and remote trigger)

•Telemetry

Cost: $6650 base system + approx. $6000 for glove

Website: http://www.nexgenergo.com/ergonomics/nexglove.html

Brochure? No

5.1.14 Range of Motion

5.1.14.1 Analog Inclinometers

Universal Inclinometer

The Universal Inclinometer replaces the goniometer for quick and easy measurements.The inclinometer is fluid dampened to permit fast, accurate readings without waiting for oscillations to damp out. The inclinometer is easily adjusted to zero at the initial position so the final reading is the range of motion. A short base is provided for measuring curved surfaces like the spine.

A long base works well for placement on long flat surfaces such as the arm (when measuring elbow range of motion) or the leg (when measuring knee range of motion). The long arm is also easy to grasp for measurements such as wrist rotation and shoulder rotation.

When measuring the extremities one inclinometer is sufficient. When measuring the spine the two inclinometer method (dual inclinometry) is preferred.

Cost: $90 each

Advantages:

- Ball indicator reduces sensitivity to vertical orientation
- Three inch dial is readable to one degree
- Retains all features of the Universal Inclinometer
- Rubber footed base grips curved surfaces
- Long arm base can be used for extremity measurements
- Long arm base can be easily gripped for wrtist rotation measurements

Disadvantage:

• Single sided, affected by gravity
Manufacturers: Rehab Outlet Website: http://www.rehaboutlet.com/inclinometers.htm Brochure? No

5.1.14.2 Digital Inclinometers

Universal Inclinometer Acumar Single Digital Inclinometer: The Acumar Single Digital Inclinometer is a compact, handheld unit that features a large digital display for easy reading. Store measurements with the hold button, and review maximum, minimum and average values. This full featured unit reduces examination time and enhances the objectivity of measurement and documentation. Supports range of motion evaluation as described in the AMA Guides to the Evaluation of Permanent Impairment. Inclinometer comes with built-in wireless transmitter to optional computer interface.When measuring the extremities one inclinometer is sufficient. When measuring the spine the two inclinometer method (dual inclinometry) is preferred. Acumar Dual Digital Inclinometer: Package contains Acumar Single Digital Inclinometer and Companion Unit. Also comes with case and connecting cable. Two-inclinometer technique and procedure is well defined in the 5th Edition of AMA Guides. Acumar Dual Inclinometer contains modern features that simplify measurements and increase objectivity. Acumar Dual Inclinometers can simultaneously capture both angles by the press of a single button. It allows up to six pairs of data for viewing and recording to greatly speed up data capture and analysis.
Cost: $285 for one, $525 for the dual set
Advantages: • Reduces examination time, enhances accuracy

Disadvantage: • Prone to battery failure
Manufacturers: Rehab Outlet Website: http://www.rehaboutlet.com/inclinometers.htm Brochure? No

5.1.15 Soldier Performance Measures

5.1.15.1 Automated Target Scoring Systems: Weapons Trainers

For physical ergonomics studies involving weapons, performance measures can be taken from the speed and accuracy of target shooting. This can be done by a weapons trainer (e.g. Canadian Forces Fire Arms Trainer (FAT)) using instrumented weapons that are typically tethered with an umbilical cable that supplies air effects, power, and communications with a virtual reality system.

Available configurations: Systems can be configured for 50+ weapons.
Scenarios are created and displayed on a screen. Output could be target scoring and elapsed time.
The advantages include dynamic targets, realistic scenarios and targets, and no expenditure of ammunition. There is no safety risk or need for a Range Safety Officer. The system can be set up and left in a dedicated room.
The disadvantages are lower fidelity, and lower realism when compared to actual shooting or combat situations. These systems are intended for training and not for scientific gathering of shot data. Usually a limited number of shooters at a time (e.g. 3 lanes at once). Scenarios are not typically set up for accurate shot timing information – instead, a combat scenario is presented for training.

Example Manufacturers: Meggitt: http://www.meggitttrainingsystems.com/main.php?id=2 CAPS: http://www.caps-inc.com/default.aspx Brochure? Yes

5.1.15.2 Automated Target Scoring: Live Fire Systems

For physical ergonomics studies involving weapons, performance measures can be taken from the speed and accuracy of shooting. This can be done during live fire using an automated target scoring system. Participants fire at the target and acoustics are used to capture the accuracy and timing of every shot taken in a firing sequence.

Available configurations: Systems can be configured for any type of rifle that shoots at a target. Targets can be controlled (i.e. UP or DOWN) and the distance can be variable (typically 25 yards, long range shooting is 100 yards).
Shooting scenarios (e.g. pivot and fire, Mozambique drill, extended hold) are planned ahead of time so that data collection can be automatically aggregated in a spreadsheet. Output data includes accuracy of shot, shot grouping, and shot timing.
The advantages include actual rifle firing (not simulation), very accurate results, and the ability to gather large amounts of data: many scenarios are possible with multiple participants on a multi-lane range.
The disadvantages are that shooting is limited to a target range, not combat scenarios. A rifle range is required. These systems require considerable set-up.

Example Manufacturers: TDCUE system (by AAI): http://www.aaicorp.com/products/advanced_prog/acoustic_detection.html TAG 2000: http://dl-ruilong.en.alibaba.com/ Brochure? Yes - TDCUE

5.1.15.3 Obstacle Courses

Obstacle courses can be used to study how the weight, bulk, and stiffness of a load placed on the infantry soldier affects combat performance. The obstacle courses can be modular and can consist of sequential test segments. They can be instrumented at varying degrees of sophistication from stopwatches to Radio Frequency Identification (RFID) race timing mats. Additional stations can be added such as jump and weight transfer.

Available configurations: There can be an endless number of obstacles created, indoor or outdoor. Some examples include: 1) Inner and outer courtyard walls 2) Windows 3) Low crawl 4) Tunnel and hatch 5) Stair and ladder 6) Balance beam 7) Sprint 8) Agility run 9) Casualty drag 10) Bounding rushes
Examples: MCLEAP, GRIIT, indoor obstacle course (e.g. wooden structures at CFB Shilo, MB), outdoor obstacle course (e.g. MCB Kaneohe Bay). The advantages and disadvantages

between them are discussed below.

CFLEAP (Canadian Forces Load Effects Assessment Program):

The CFLEAP is an obstacle course that is modular and consists of sequential test segments which are instrumented by Radio Frequency Identification (RFID) race timing mats. Additional stations can be added such as jump and weight transfer.

Advantages: Accurate instrumentation - jump mats and RFID boxes with timing mats are used to precisely time the obstacles. Outdoor modular setup; can be stored and shipped as a unit.

Disadvantages: Requires considerable setup, more expensive due to instrumentation and modularity.

Indoor Obstacle course (e.g. wooden structures at CFB Shilo, MB):

An indoor obstacle course typically modular and can consist of sequential test segments. They can be instrumented at varying degrees of sophistication however the most basic form of measurement is timing by stopwatches.

Advantages: Inexpensive, modular.

Disadvantages: No accurate instrumentation other than stopwatches, low realism when compared to actual combat situations.

Outdoor Obstacle Course (e.g. at MCB Kaneohe Bay):

An outdoor obstacle course usually more rugged than indoor structures however they are permanent structures and not modular. They consist of sequential test segments, and can be instrumented at varying degrees of sophistication however the most basic form of measurement is timing by stopwatches.

Advantages: More robust than indoor wooden structures, more realistic than indoor wooden structures, relatively inexpensive.

Disadvantages: Not modular, remains in place, no instrumentation other than stopwatches, low realism when compared to actual combat situations.

Combat Simulator (e.g. GRIIT Gruntworks Research Infantry Integration Testing):

The combat simulator is an indoor realistic environment that provides combat training using various scenarios displayed on screens in many different rooms. A wireless replica weapon is instrumented, and camera systems are used to measure time and accuracy of combat tasks and shooting. A control room allows for 3D virtual playback of the scenario (after action review).

Advantages: Extremely realistic to combat scenarios. Instrumented with camera system that allows 3D playback in a virtual environment. Capacity for detailed analysis of every motion.

Disadvantages: Not modular, high cost, not meant to measure physical exertion limits.

5.1.15.4 Motion Reality Force Simulation: VIRTSIM

VIRTSIM is a training simulator that immerses soldiers in a virtual reality environment, and has capacity to export data including 3D playback in a virtual environment, biomechanical forces/torques, and weapon firing data. VIRTSIM immerses up to twelve squad members and one trainer/officer in visually accurate, live combat scenarios requiring real-time individual, team and squad-level fire and manoeuvre. Unlike screen and other simulators, the trainee's entire body is immersed in and is a part of the combat. Trainees are vulnerable to 360° threats from snipers, ambush teams, explosive devices and even "friendly-fire." Soldiers being trained in VIRTSIMTM are faced with the most intense training experience possible outside of actual combat.

The base VIRTSIMTM system site is 50' x 100' x 15' (15.25m x 30.50m x 4.6m). VIRTSIM-HT (VIRTSIM High Throughput) is designed to maximize the amount of trainees that can utilize the system and optimize the flow of training groups through the system. This enhanced configuration layout allows approximately 1,000 trainees to be trained every 40 hours. Notable additions to the base system include a Trainee Prep Area, 3D Real-Time Scale System, and an After-Action Review Room. VIRTSIM sizes and configurations can be tailored to trainers' needs and environmental requirements (minimum size system is 30' x 40' x 10').
All shots fired by every character are recorded and displayed instantly with the time each shot was taken, the trainee's name that fired the shot, the distance at which the shot was fired, and the body part that was hit. Individual Shot Summaries with Accuracy Percentages are generated Dynamic Display of Trainees' and Combatants' Lines of Fire That Turn from Green to Red When Shots are Fired Display 60 degree Sectors of Responsibility for Each Trainee Instantly save a simulation in 3D Replay the exercise from any 3rd person perspective view Replay the exercise from any live or AI character's 1st person perspective view Dynamically display trainee's names over their heads as they move for easy identification Instantly calculate trainee(s)' shooting accuracy Also, there is capability for biomechanical forces/torques and shot accuracy/timing data – however this is not advertised on the website (possibly not configured yet?)

The advantages VIRTSIM: • High realism to combat situation • Allows 3D playback in a virtual environment. Capacity for detailed analysis of every motion. • Ammunition Costs: Significant savings from reduced time spent in live fire training, as well as savings on ammunition during VIRTSIM training since weapons are battery powered. • "Green" Savings: Simulate live ammunition firefights, IED explosions, and other destructive combat activities without the recurring costs of repairs due to collateral damage to the training environment. •
The disadvantages VIRTSIM: • Meant as a training system - the capability for data output (e.g. for biomechanical forces/torques or shot timing/accuracy on a target) is mentioned verbally by the company representative, but not advertised or confirmed. • Not able to test physical exertion limits (e.g. crawl through a window)
Website: http://forcesimulation.motionrealityinc.com/index.html Brochure? No

5.2 Measurement: System Integration

5.2.1 3D Environment Scanning

5.2.1.1 Leica HDS6200

Leica offers a product family of 3D environment scanners. For physical ergonomics applications (e.g. inside vehicle crewstations or workstations) a short-range “pulse” scanner is recommended. (short range would be 0-75m, long range would be up to 1000m). The Leica HDS6200 is a short-range pulse scanner that features several major "next generation" advances that increase the versatility, portability, and productivity of ultra high-speed, phase-based laser scanning for many plant, architectural and heritage as-built survey applications.

Leica HDS6200:

Instrument type Compact, phase-based, dual-axis sensing, ultra high-speed laser scanner, with survey-grade accuracy and full field-of-view
User interface Onboard touch panel, or external notebook or Tablet PC, or PDA
Scanner drive Servo motor
Data storage Integrated hard drive
Camera No integrated camera; Cyclone SCAN supports use of external camera

Accuracy of single measurement
Position*
Distance*
Angle (horizontal/vertical)
5 mm, 0.4 m to 25 m range;
9 mm to 50 m range
δ2 mm at 90% albedo up to 25 m;
δ3 mm at 18% albedo up to 25 m
δ3 mm at 90% albedo up to 50 m;
δ5 mm at 18% albedo up to 50 m
125 µrad/125 µrad, one sigma
Modeled surface precision/noise**
1 mm at 25 m; 2 mm at 50 m for 90% albedo, one sigma;
2 mm at 25m; 4 mm at 50m, for 18% albedo, one sigma
Target acquisition* 2mm std. deviation
Dual-axis sensor Selectable on/off; 3.6" resolution
Data integrity monitoring
Self-check at start-up;
optional checks using Cyclone-SCAN

Type Phase-shift
Laser Class 3R (IEC 60825-1)
Range 79 m ambiguity interval
79 m @90%; 50 m @18% albedo
Scan rate Up to 1,016,727 points/sec, maximum instantaneous rate
Scan resolution
Spot size
Selectability
"Preview"
Middle (4x)
High (8x)
Super High (16x)
Ultra High (32x)
3 mm at exit (based on Gaussian definition) + 0.22 mrad divergence;
8 mm @25 m; 14 mm @50 m
5 pre-set spacings per table
Pts/360° Scan time Point spacing

(vert., horiz.) (full dome) at range @10 m
1250 25 sec 50.6x50.6 mm
5000 1 min 40 sec 12.6 x 12.6 mm
10000 3 min 22 sec 6.3 x 6.3 mm
20000 6 min 44 sec 3.1 x 3.1 mm
40000 26 min 40 sec 1.6 x 1.6 mm
Field-of-view
Horizontal
Vertical
Aiming/Sighting
360° (maximum)
310° (maximum)
Optical horizontal sighting using QuickScan™ feature
Scanning Optics Vertically rotating mirror on horizontally rotating base;
User selectable vertical rotation speed (12.5 rps, 25 rps or 50 rps);
Environmentally protected by shield
Scan motors Direct drive, brushless; proprietary
Data transfer Ethernet or USB 2.0 device (two ports)
Data storage
capacity (onboard) 60 GB, min
Communications Ethernet or integrated Wireless LAN (WLAN)
Status indicators 4-line alphanumeric display for laser status, system power & status
1 LED for laser status
Level indicator External bubble; digital readout on touch panel or via laptop

Power supply 24 V DC; 90 – 260 V AC
Power
Consumption 65 W max.
Battery Type Integrated: Li-ion, External: sealed lead acid
Duration Internal: 2.5 hrs, typical, External: 4 hrs, typical
Power status LEDs indicate charging status and capacity levels

Operating temp. -10° C to +45° C
Storage temp. -20° C to +50° C
Lighting Fully operational between bright sunlight and complete darkness
Humidity Non-condensing
Reflectivity no retro-reflectors

Scanner
Dimensions
Weight
7.8”D x 11.6” W x 16.5” H, 199 mm D x 294 mm W x 360 mm H
14 kg, nominal (includes integrated battery)
Battery (external)
Dimensions
Weight
9.5” D x 10” W x 12” H, 240 mm D x 260 mm W x 300 mm H
16 kg, nominal
AC Power Supply
Dimensions
Weight
9.5” D x 5” W x 6” H, 240 mm D x 127 mm W x 152 mm H
2.5 kg, nominal

Scanner and accessory carrying case
Additional rechargeable integrated battery
Charging/power cable, ethernet cable, A/C cable
Battery charger / A/C power supply
Battery charging cradle for internal battery
Cyclone™-SCAN software
Cleaning kit

Notebook PC, Tablet PC, or PDA
HDS6200 scan targets and target accessories
Service agreement for Leica HDS6200
Extended warranty for Leica HDS6200
External camera kit (third party product)

Component
Processor
RAM
Network card
Display
Operating system
required (minimum)
1.7 GHz Pentium M or similar
1024 MB SDRAM (2 GB for Vista)
Ethernet
SXGA+ (64 MB or greater video RAM rec.)
Windows XP Professional (SP2 or higher) (32 or 64)
Windows Vista (32 or 64)

Cost: Approx $80,000 to $100,000 depending on options and software

The advantages Leica: • High scan rate, range, and scan resolution. • Leica is the industry standard (over 50% of market share)
Website: http://hds.leica-geosystems.com/en/Leica-HDS6200_64228.htm Brochure? Yes

5.2.1.2 DeltaSphere 3000 3D Laser Scanner

Scan a crime scene, a movie set, or a building under construction with the DeltaSphere-3000 3D Scene Digitizer. Capture millions of measurements with high-resolution, digital color to match. Lightweight, fast, and surprisingly easy to use - the DeltaSphere-3000 makes 3D scanning affordable and accessible for your application.

Integrated Hardware Components:

Time-of-flight, modulated beam, laser range finder;

Class 3R - 780nm infrared laser, 8mW. max

Embedded CPU with Ethernet

Elevation and azimuth positioning subsystems

Separate AC power supply and DC cable included. Can run off a car batter or an auxiliary rechargeable battery

Standard photographer's and surveyor's tripod mounts

High-quality shipping case included

Color option includes professional digital camera, lens and camera mount

Integrated Software (for user supplied PC):

Interactive scanning control specifying FOV, speed, and resolution

Data storage, preview and measuring tool. View range data during and after scanning

Conversion to 3D points and creation of high-quality 3D models, in grayscale or color

Compatible with popular polygon conversion software. Export to InnovMetric PolyWorks/Modeler, Inus RapidForm, and Pointools View as well as VRML and ASCII XYZ

Color option includes camera control, IEEE 1394 or USB2.0 image capture

DeltaSphere-3000 / DeltaSphere-3000IR Performance

Average Data Acquisition	15,466 point per second
Max Data Acquisition	24,000 point per second
Typical Time for 360° Scan	12 min.
Range	1ft (0.3m) - 54 ft (16m)
Distance Accuracy	0.2 in (5mm)
FOV - Horizontal	360°
FOV - Vertical	290°
Angular Accuracy	0.015°

Scan Density	5-15 points per degree
Beam Diameter	0.1in at 0ft; 0.28in at 30ft

System Specifications

Dimensions	14" x 14" x 4" (0.35m x 0.35m x 0.1m)
Weight	22 lbs. (10 kg); 48 lbs. with shipping case
AC Power Requirements	100-240 V (40-65w)
DC Power Requirements	12 V (40-65w)
Operating Temp.	0° - 45° C
Humidity	Non-condensing atmosphere
PC Requirements	Windows XP, 256Mb Memory
Warranty	1 year

Cost: $29,400. The color option, which includes a high quality color digital camera, lens and additional software, is $10,000. Turnkey systems with a high-end graphics laptop, tripod, and training on site is typically about $52,000.

DeltaSphere is lower cost than Leica. However it has lower range, scan rate, and scan resolution than Leica.

Website: http://www.deltasphere.com/deltasphere3000_specs.htm

Demo video: www.deltasphere.com/outgoing/DeltaSphere-13Sep10.wmv

Brochure? No

5.2.2 3D Handheld Laser Scanners

5.2.2.1 Creaform

Creaform.offers a suite of portable, self-positioning handheld laser scanners, with a wide range of functionality and cost.

Handyscan 3D scanners are completely portable, free standing, handheld scanners and are the only self-positioning scanners capable of generating real time STL files. This eliminates point cloud processing and the need to purchase costly tracking devices such as a CMM or measurement arm.

Sales representatives suggested the Handyscan 3D scanners known as the REVscan, EXAscan, VIUscan, MAXscan would most likely be suited for applied ergonomics applications.

HANDYSCAN 3D COMPARISON MATRIX

KEY DIFFERENTIATORS		UNISCAN	REVSCAN
		ENTRY-LEVEL ($ AND FUNCTIONALITIES)	AFFORDABLE PRICE ($), VERY STRAIGHTFORWARD USE
APPLICATIONS	REVERSE ENGINEERING, STYLING AND DESIGN	+	++
	INSPECTION		+
	FEA/CFD	+	++
	3D VIRTUAL CONTENTS IN COLOUR		
	PROTOTYPING	+	++
INDUSTRIES	AUTOMOTIVE/TRANSPORT	√	√
	MUSEOLOGY/HERITAGE PRESERVATION		
	ARCHITECTURE		
	AEROSPACE		√
	CONSUMER PRODUCTS	√	√
	MANUFACTURING	√	√
	MULTIMEDIA		
SOFTWARE		VXelements Express	VXelements
WEIGHT		980 grams (2.1 lbs.)	980 grams (2.1 lbs.)
DIMENSIONS		160 x 260 x 210 mm (6.25 x 10.2 x 8.2 in.)	160 x 260 x 210 mm (6.25 x 10.2 x 8.2 in.)
MEASUREMENT		18,000 measures/s	18,000 measures/s
LASER CLASS		II (eye-safe)	II (eye-safe)
RESOLUTION		0.100 mm (0.004 in.)	0.100 mm (0.004 in.)
ACCURACY		Up to 0.060 mm (0.003 in.)	Up to 0.050 mm (0.002 in.)
VOLUMETRIC ACCURACY*		0.050 mm + 0.250 mm/m (0.0020 in. + 0.0030 in./ft)	0.020 mm + 0.200 mm/m (0.0008 in. + 0.0024 in./ft)
DEPTH OF FIELD		30 cm (12 in.)	30 cm (12 in.)
TEXTURE RESOLUTION		n/a	n/a
TEXTURE COLORS		n/a	n/a
PART SIZE RANGE (RECOMMENDED)		+5 m 4 m 3 m 2 m 1 m	

HANDYSCAN 3D COMPARISON MATRIX



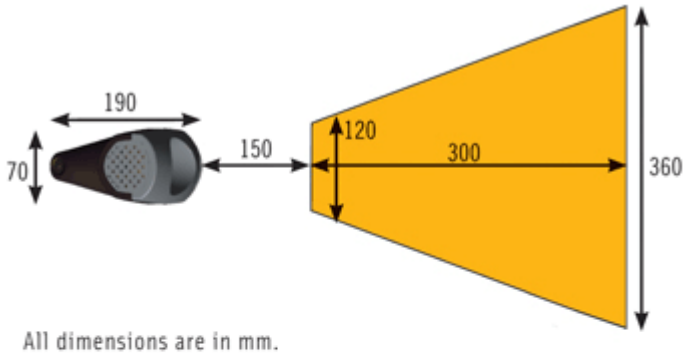
KEY DIFFERENTIATORS		EXASCAN	MAXSCAN	VIUSCAN
		HIGH RESOLUTION AND ACCURACY	HIGH ACCURACY FOR LARGER PARTS	COLOUR
APPLICATIONS	REVERSE ENGINEERING, STYLING AND DESIGN	++	++	++
	INSPECTION	+++	+++	+
	FEA/CFD	++	++	+
	3D VIRTUAL CONTENTS IN COLOUR			+++
	PROTOTYPING	++	++	++
INDUSTRIES	AUTOMOTIVE/TRANSPORT	√	√	√
	MUSEOLOGY/HERITAGE PRESERVATION			√
	ARCHITECTURE			√
	AEROSPACE	√	√	√
	CONSUMER PRODUCTS	√	√	√
	MANUFACTURING	√	√	
	MULTIMEDIA			√
SOFTWARE		VXelements	VXelements	VXelements
WEIGHT		1.25 kg (2.75 lbs.)	1.27 kg (2.80 lbs.)	1.3 kg (2.85 lbs.)
DIMENSIONS		172 x 260 x 216 mm (6.75 x 10.2 x 8.5 in.)	172 x 260 x 216 mm (6.75 x 10.2 x 8.5 in.)	172 x 260 x 216 mm (6.75 x 10.2 x 8.5 in.)
MEASUREMENT		25,000 measures/s	18,000 measures/s	18,000 measures/s
LASER CLASS		II (eye-safe)	II (eye-safe)	II (eye-safe)
RESOLUTION		0.050 mm (0.002 in.)	0.100 mm (0.004 in.)	0.100 mm (0.004 in.)
ACCURACY		Up to 0.040 mm (0.0016 in.)	Up to 0.050 mm (0.002 in.)	Up to 0.050 mm (0.002 in.)
VOLUMETRIC ACCURACY*		0.020 mm + 0.100 mm/m (0.0008 in. + 0.0012 in./ft)	0.020 mm + 0.025 mm/m (0.0008 in. + 0.0003 in./ft)	0.020 mm + 0.200 mm/m (0.0008 in. + 0.0024 in./ft)
DEPTH OF FIELD		30 cm (12 in.)	30 cm (12 in.) (Scan)	30 cm (12 in.)
TEXTURE RESOLUTION		n/a	n/a	50 to 250 DPI
TEXTURE COLORS		n/a	n/a	24 bits, SRGB-calibrated
PART SIZE RANGE (RECOMMENDED)				+15 ft. 12 ft. 9 ft. 6 ft. 3 ft.

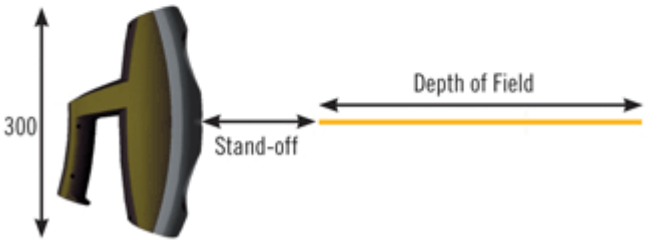
Cost: REVscan: $41,900 (original scanner) EXAscan: $51,900 (high accuracy & resolution) VIUscan: $51,900 (color scanner) MAXscan: $76,900 (for large parts)
The advantages Creaform: • Large range of products – customized for our applications • High resolution and accuracy is possible
Website: http://www.creaform3d.com/ Brochure? Yes

5.2.2.2 NDI VicraSCAN

VicraSCAN™ handheld 3D laser scanner is an all-in-one, self-positioning handheld 3D laser scanner. Using unique self-positioning technology and small reference targets, setup is a snap since no other tracking device is required. Simply plug the lightweight, ergonomic scanner into an available USB port and scan directly into powerful 3rd party software packages without the need to save and import data first. Truly portable, you can measure virtually anywhere with greater freedom and control using the VicraSCAN handheld 3D laser scanner.

VicraSCAN Measurement Volume:





Dimensions (L x W x H)	190 mm x 70 mm 300 mm	

Weight	845 g
VicraSCAN Sensor Specifications	
Profile Density	486 points/line
Update Frequency	30 Hz
Scan Rate	14, 580 points/second
Stand-off	150 mm
Depth of Field	300 mm
Near Field Width	120 mm
Far Field Width	360 mm
Safety	Class 2, 635 nm laser

Use 3D data to rapid prototype, recreate, reproduce, restore and model parts

Create 3D digital mock-ups and virtual environments for animation, advanced visualization, multimedia applications, and complex assembly instructions

Cost: $48,000. This is a complete system that includes software that will export .stl files.

Advantages/Disadvantages of NDI VisraSCAN:

- High resolution and accuracy
- Only one product (not a family)

Website: http://www.ndigital.com/industrial/vicrascan-3D-laser-scanner-applications.php

Brochure? Yes

5.2.3 3D Point Measuring

5.2.3.1 Coordinate Measuring Machines (CMMs)

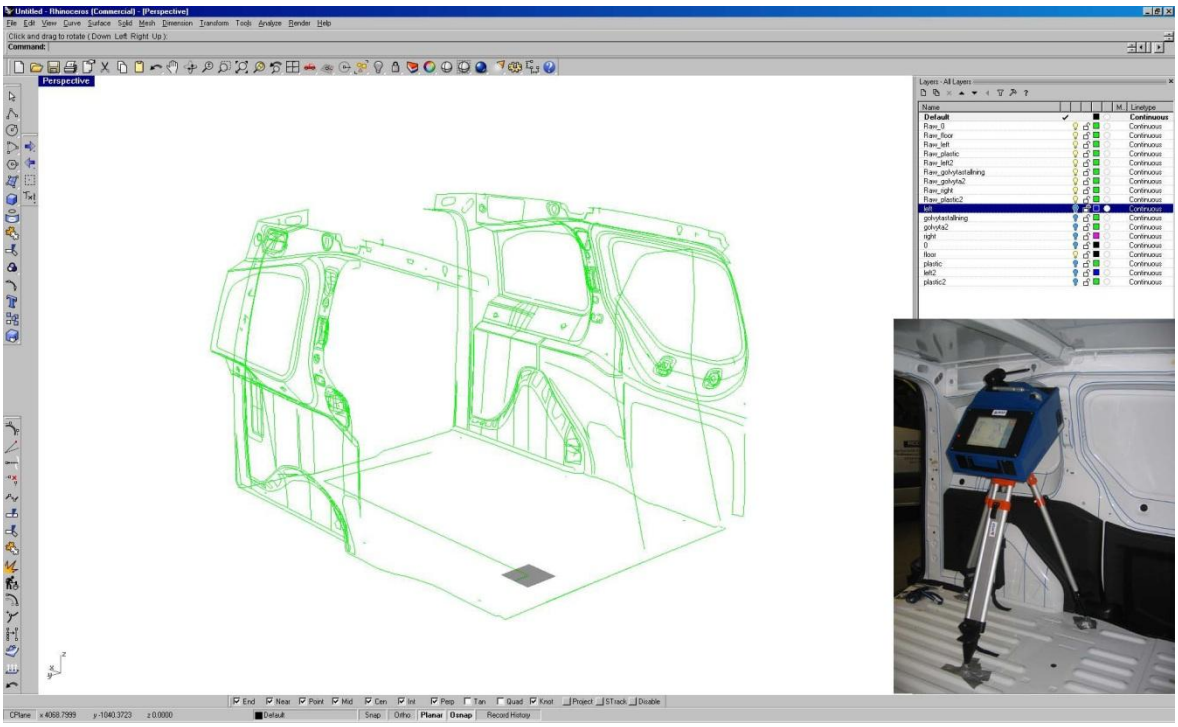
A Coordinate Measuring Machine (CMM) is used to perform high accuracy 3D measurements of parts. In a R&D setting, they are typically set up in a laboratory and used for multiple applications (e.g. measuring prototypes). In a production environment, they are a programmed piece of machinery in an automated tooling system, and used to perform repeated quality control checks on parts. They are highly accurate and dependable, however they are not portable and are limited to the size envelope of the robotic arm and measurement table.

A R&D shop should have a manual CMM and a production environment requires a programmable unit.
Cost: $20,000 to $500,000 depending on manual/programmed operation, probing system, size, resolution, accuracy, repeatability, type of bearings, etc.
Multiple Manufacturers, all offering a product family of sizes, manual/programmed, etc: Websites: • Brown & Sharpe • LK Metrology • Mahr Federal Inc. • Mitutoyo • Renishaw • Starrett • Werth America Inc. • Zeiss Brochure? No

5.2.3.2 Portable Coordinate Measuring Machine (CMM): Prodim Proliner

A Coordinate Measuring Machine (CMM) is used to perform high accuracy 3D measurements of parts. A portable CMM can be used for re-engineering workstations, vehicle crewstations etc.

The Proliner® has a measuring head that can be rotated in every direction and has a wire that can be stretched out for several meters. At the end of the wire is a metal measuring pen. With this measuring pen you can simply mark the relevant points. These points are directly translated into a digital DXF CAD file. With the Proliner® you can measure straight, curved and very complex shapes in an instant. You can measure any object in horizontal, vertical or slanting position.



The Proliner comes in a 2D or 3D solution.
Cost: $25K

Wire Length: 7.5 Meter

Software:

- 2D or 3D measuring
- CAD functions: extended
- Dimension point-point
- Other dimensions
- Layers
- Leap Frog (for endless range)
- Notes
- Calculator
- DXF Output
- CCD Output
- TXT Output

- Size: 190x380x325 mm
- Screen size: 8.4”
- Weight: 10 kg
- 10,8 V battery
- Socket connection: 220 V /

110 V, 50 /60 Hz

The advantage to the Proliner is the portability, compact size, and relatively low cost. One disadvantage is that the pen must be in a straight line of sight to the system (i.e. the wire must be straight), making it difficult to measure around seatbacks etc.

Website: http://www.prodim-proliner.eu/pagina/1/deactief/1288606414111/Home

Brochure? Yes

5.2.3.3 FaroArm

The FaroArm is a portable Coordinate Measuring Machine (CMM) that is used to perform high accuracy 3D measurements of parts. Unlike the Proliner the arm has the ability to measure around corners. A portable CMM can be used for re-engineering workstations, vehicle crewstations etc.

Performance Specifications

Model (Range)	Volumetric Accuracy		Single Point Repeatability		FaroArm Weight	
axis	6	7	6	7	6	7
6 ft. (1.8 m)	**±.0009 in. (±.023 mm)**	**±.0011 in. (±.027 mm)**	.0006 in. (.016 mm)	.0007 in. (.019 mm)	20.5 lbs. (9.3 kg)	21 lbs. (9.5 kg)
8 ft. (2.4 m)	**±.0010 in. (±.025 mm)**	**±.0011 in. (±.028 mm)**	.0007 in. (.018 mm)	.0008 in. (.020 mm)	21 lbs. (9.5 kg)	21.5 lbs. (9.75 kg)
10 ft. (3.0 m)	**±.0018 in. (±.046 mm)**	**±.0022 in. (±.055 mm)**	.0013 in. (.032 mm)	.0015 in. (.039 mm)	21.5 lbs. (9.75 kg)	22 lbs. (9.98 kg)
12 ft. (3.7 m)	**±.0024 in. (±.060 mm)**	**±.0028 in. (±.072 mm)**	.0017 in. (.043 mm)	.0020 in. (.051 mm)	22 lbs. (9.98 kg)	22.5 lbs. (10.21 kg)

FaroArm Test Methods - (Test methods are a subset of those given in the B89.4.22 standard.)

Volumetric Accuracy or Volumetric Maximum Deviation: *Determined by using traceable length artifacts, which are measured at various locations and orientations throughout the working volume of the FaroArm. This test is a method for determining articulating measurement machine accuracy.*

Single Point Repeatability or Single Point Articulation Performance Test (Max-Min)/2: *The probe of the FaroArm is placed within a conical socket, and individual points are measured from multiple approach directions. Each individual point measurement is analyzed as a range of deviations in X, Y, Z. This test is a method for determining articulating measurement machine repeatability.*

Hardware Specifications

Operating Temp range:	10°C to 40°C (50°F to 104°F)	**Operating Humidity Range:**	0-95%, noncondensing
Temperature Rate:	3°C/5min. (5.4°F/5min. Max)	**Power Supply:**	Universal worldwide voltage 85-245VAC, 50/60 Hz

Faro recommends the "Fusion" for physical ergonomics applications because accuracy is OK at .001 inches (i.e. we are not doing precision machining). The 8 foot / 7axis arm is recommended. It has a 6"x6" mounting surface.

A product demonstration is recommended.

Cost:

a) Could be outsourced for each job
b) Probe system: $52,000 ($35,000 for arm, $15,000 for software, mounting, and on-site training, $2000 for mounting with magnetic base)
c) Probe and Scanner attachment (for surface scanning): $74,000 ($35,000 for arm, $20,000 for software, $17,000 for scanning head, $2,000 for mounting)

The advantage to the FaroArm is the ability to measure around corners. One disadvantage is the arm size is too large to easily fit into tight spaces, such as vehicle crewstations.

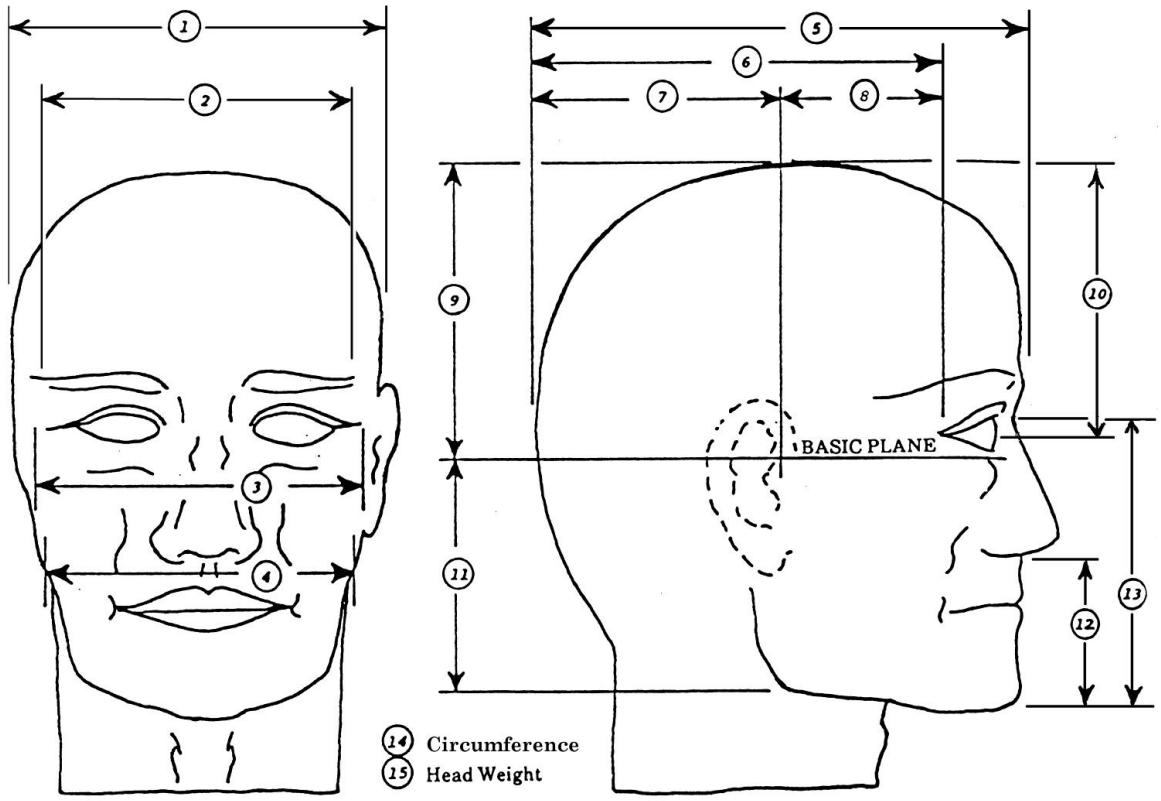
Website: http://www.faro.com/FaroArm/Home.htm

Brochure? Yes

5.2.4 Headforms, Dummies, Mannequins

5.2.4.1 NOCSAE (National Operating Committee on Standards for Athletic Equipment) Headform

The NOCSAE standard for headwear is a biofidelic headform with a glycerin-filled brain cavity. It is intended for drop testing for impact injury assessment, according to a NOCSAE laboratory protocol.



DIMENSIONING OF NOCSAE HEAD MODELS
(See Table 1)

Figure 1

APPROXIMATE MEASUREMENTS OF NOCSAE HEADFORMS † - inches (mm)
(See Figure 1)

POINTS OF MEASURE	HEADFORM SIZES		
	6 5/8	7 1/4	7 5/8
1 Head Breadth	5.63 (143)	5.98 (152)	6.46 (164)
2 Maximum brow width (frontal diameter)	4.65 (118)	5.20 (132)	5.52 (140)
3 Ear hole to ear hole (bitragion diameter)	5.24 (133)	5.51 (140)	6.06 (154)
4 Maximum jaw width (bigonial diameter)	4.13 (105)	4.65 (118)	5.08 (129)
5 Head length (glabella landmark to back of head)	7.09 (180)	7.87 (200)	8.15 (207)
6 Outside eye corner (external canthus) to back of head	6.22 (158)	6.81 (173)	7.32 (186)
7 Ear hole (tragion) to back of head	3.50 (89)	3.86 (98)	4.25 (108)
8 Ear hole to outside corner of eye (tragion to ext. canthus)	2.72 (69)	2.95 (75)	3.07 (78)
9 Ear hole to top of head (tragion to vertex)	4.72 (120)	5.24 (133)	5.67 (144)
10 Eye pupil to top of head	4.13 (105)	4.53 (115)	4.96 (126)
11 Ear hole ‡ to jaw angle (tragion to gonion)	3.31 (84)	3.03 (77)	2.84 (72)
12 Bottom of nose to point of chin (subnasal to menton)	2.56 (65)	2.80 (71)	3.03 (77)
13 Top of nose to point of chin (nasion to menton)	4.45 (113)	4.88 (124)	5.39 (137)
14 Head circumference	21.02 (534)	22.68 (576)	24.17 (614)
15 Head weight including mounting interface	9.08 lb (4.12 kg)	10.8 lb (4.90 kg)	13.08lb (5.93 kg)

The NOCSAE headform is a head and neck complex only. It is the standard for sport helmet testing, and if a helmet passes the standard laboratory drop test, a helmet manufacturer can advertise that compliance with NOCSAE is met.
NOCSAE develops performance standards for protective equipment used in a variety of sports. All NOCSAE standards and laboratory guides are available online.
Website: http://www.nocsae.org/standards/documents.html Brochure? No

5.2.4.2 Vehicle Crash Testing Anthropometric Test Dummies (ATDs)

Automotive manufacturers developed every one of its crash dummies to respond to a particular need for a test measurement and enhanced safety design. Engineers required a test device that would allow them to take measurements in unique experiments they had developed to improve the safety of vehicles. The goal of the Hybrid III research group was to develop a third-generation, human-like crash test dummy whose responses were as close as possible to biomechanical data.

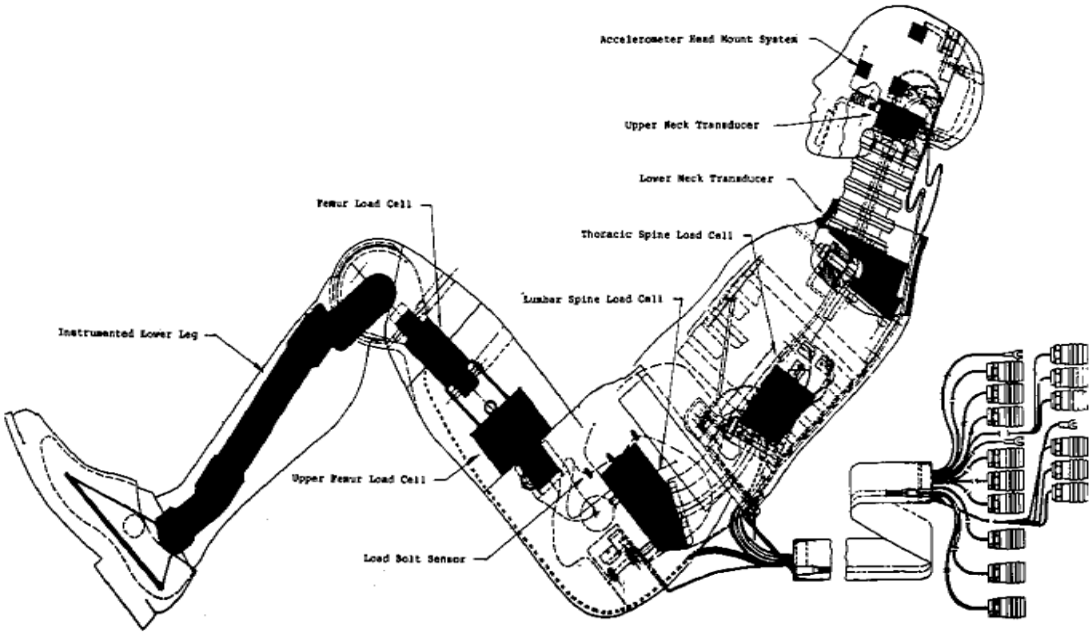
Researchers studied the way people sat in vehicles and the relationship of their posture to their eye position. They experimented with and changed the materials to make the dummy, and considered adding internal elements such as a rib cage. The stiffness of materials reflected biomechanical data. Accurate, numerical control machinery was used to manufacture the improved dummy consistently.

In 1977, GM made Hybrid III commercially available, including all the new design features GM had researched and developed.

Over the years, Hybrid III and other dummies have undergone a number of improvements and changes. For example, GM developed a deformable insert that is used routinely in GM development tests to indicate any movement of the lap belt from the pelvis and into the abdomen. Also, the SAE brings together the talents of the car companies, parts suppliers, dummy manufacturers and U.S. government agencies in cooperative efforts to enhance test dummy capability.

In the 1990s, the U.S. auto industry worked to create a special, small occupant dummy to test side-impact air bags. Through USCAR, a consortium formed to share technologies among various industries and government departments, GM, Chrysler and Ford jointly developed SID-2s.

GM researchers constantly refine all aspects of the crash tests to improve safety results. For example, as restraint systems help to eliminate more and more catastrophic upper-body injuries, safety engineers are noticing disabling lower-leg trauma. GM researchers are beginning to design better lower leg responses for dummies. They have also added "skin" to the necks to keep air bags from interfering with the neck vertebrae during tests.



The Hybrid III is a full-body ATD (Anthropometric Test Dummy) although parts can be customized and used individually for specific laboratory tests (e.g. the headform can be attached to a stand and used as a base for mass properties studies). It is the standard for motor vehicle crash testing. It is instrumented to show compliance in a crash test (e.g. accelerometers tell what the change in velocity at a specific body location). Government bodies such as NHTSA (National Highway Traffic Safety Administration) produce requirements for vehicles based on Hybrid III results, as well as other ATDs such as SID (Side Impact Crash Test Dummy) and BioRID (Rear Impact Crash Test Dummy). Website: http://www.nhtsa.gov/
Manufacturers: Denton, FTSS Distributor: http://www.humaneticsatd.com/

5.2.4.3 ISO Headforms

ISO Headforms are meant for impact testing of US and Canadian Industrial Headwear.

The cast urethane half headforms are used for impact attenuation testing. It is designed and manufactured to meet ANSI Z89.1 and CSA Z94.1 safety helmets standards. The headforms are shaped as per ISO/DIS 6220 standards.
Material: Cast urethane; Harness: 60 +/- 6 Shore D; Shaped as per ISO/DIS 6220 standards; Sizes A, E, J and M available.
Manufacturer: Cadex (Montreal, Canada) http://www.cadexinc.com/ISO.html

5.2.4.4 General Purpose Dummies

General Purpose dummies are a low cost alternative to the various dynamic crash test dummies. These dummies expand the role of the anthropomorphic test device into many areas beyond vehicle crash testing. Since dynamic performance testing is not necessary the dummies may be produced economically.

General purpose dummies may be used for ballast dummies as well as testing harnesses, flotation devices and other similar protective gear. They are also used for training emergency response personnel in techniques of carrying people in need of rescuing on flat surfaces as well as down telephone poles and in other difficult situations. Their exterior surfaces are hard but compliant foam for an approximate human feel. They may be made buoyant for testing in water, and they may have minimal transducers and data acquisition systems mounted in them, and made waterproof. They provide a dummy for use where adherence to federally mandated dynamic performance criteria is not necessary.
General Purpose Dummies do not adhere to a specific government code.
Cost: Much less expensive than crash test ATDs because they do not have dynamic instrumentation.
Company: Humanetics http://www.humaneticsatd.com/crash-test-dummies/general-purpose-dummies

5.2.4.5 Mannequins

Mannequins are an even lower cost alternative to general purpose dummies, if biofidelity is not important. They can be useful for taking photographs of equipment on a baseline featureless human shape.

Mannequins have low biofidelity. They do not have correct mass properties and they are not designed for a particular size (e.g. 50th percentile).
Mannequins come in various sizes and do not adhere to a specific government or industry code.
Cost: Least expensive alternative – as low as $200 for a full size dummy.
Ubiquitous manufacturers. Example: http://www.mannequinstore.com/male_mannequins/featureless_male_mannequin.htm

5.2.4.6 Rescue Randy

Rescue Randy was developed for lifelike adult or juvenile victim handling, transportation, and extrication training. It has high mass and shape biofidelity.

I.A.F.F. Rescue Randy #1475

Rescue Randy #1338

Made of durable vinyl with 4,100 lb. test plastic-coated cables. Features include: articulated joints, weight distribution according to human weight distribution chart.
Used by the U.S. Military, Fire, and Police Departments, Safety Teams, and Emergency Personnel for rescue and extrication from pole top, confined spaces, collapsed buildings, smoke rooms, and ladder carry-down protocols worldwide
Cost: $1000-$1200.
Website: http://www.simulaids.com/1475.htm

5.2.5 Materials Testing Machines

5.2.5.1 Tension and Compression

Tension testers, or pull testers, are used to determine the tensile strength of various materials from metals to plastics to biomaterials. These tensile testing systems utilize various technologies to apply a range of tensile forces. Standard tensile forces can be applied with an electromechanical tensile tester while higher tension loads require a static hydraulic tensile system. Dynamic systems are a good fit for customers looking to perform fatigue tests as well as static tension tests.

Compression testers are used to determine the compressive strength of various materials from concrete to composites. These compression testing systems utilize various technologies to apply a range of compression forces. Standard compressive forces can be applied with an electromechanical tester while higher compression loads require a static hydraulic compression system.

Instron (Norwood, MA, USA) is the world leader in machines to evaluate the mechanical properties of materials and components using tension, compression, flexure, fatigue, impact, torsion and hardness tests. They offer a broad range of service capabilities, including calibration, training, technical support, and assistance with laboratory management. For both compression and tension testing, the Instron 5900 Series Universal Testing Instruments offer exceptional performance and are designed with enhancements that deliver superior accuracy and reliability, improved ergonomics, and an enhanced overall experience for the operator. The most common uses of these mechanical testing systems are for tensile and compression testing; however, they also perform bend, peel, shear, tear and cyclic tests. Various models are offered ranging from 2kN to 600 kN capacities, but the 5960 dual column tabletop systems for mid-range testing up to 50kN are ideal for biomechanical and biomaterials testing. The control panel is an integral component of the testing system, decreasing set up time and increasing testing efficiency through the use of programmable live displays and soft keys. Tests can be set up and run directly from the control panel. Two key advantages of 5940 single column systems are their small footprint and frame stiffness. The superior stiffness and alignment of the 5900 load frames ensures precise alignment when testing everything from biomaterials to wire or plastic film. The rigid mechanical design guarantees the best possible conditions for repeatable test conditions and reliable results.

Instron 5940 Single Column Tabletop System

Load measurement accuracy: +/- 0.5% of reading down to 1/500 of load cell capacity (2580 Series load cells
Up to 1 kHz data acquisition rate simultaneous on load, extension, and strain channels

Speed range of 0.05 - 2500 mm/min (0.002 - 100 in/min)
Customizable Control Panel
Compatible with Bluehill® Software
Automatic transducer recognition for load cells and extensometers
Small footprint saves space
Thousands of optional grips and fixtures
Offered in 3 model types: - 5942 with 0.5 kN (112 lbf) capacity and 726mm (28.6 in) vertical test space - 5943 with 1.0 kN (225 lbf) capacity and 1123mm (44.2 in) vertical test space - 5944 with 2.0 kN (450 lbf) capacity and 1123mm (44.2 in) vertical test space
Brochure: Yes – PDF *Website*: http://www.instron.us/wa/product/5900-Series-Single-Column-Testing-Systems.aspx

5.2.5.2 Torsion

Torsion testers, or twist testers, are used to determine the torsional properties of various components – from fasteners to biomedical devices. Instron's torsion testing line includes models for standard twist testing as well as multi-axis testing (e.g. axial/torsion.) The Instron MT Series Low Capacity Torsion testers are ideal for simulating real life service conditions, checking product quality, and evaluating biomedical material properties. Designed primarily for low-capacity (450 µNm - 225 Nm) torsion testing of materials and components, the MT torsion systems offer accurate, multi-turn capability, high rotational stiffness, and minimal axial friction. The system torque cell is attached to a movable crosshead, which can be left free-floating or clamped during testing. When left free-floating, the user can apply an axial pre-load to the specimen using a weight and pulley arrangement. Closed-loop servo-control of the electromechanical drive is provided by I-Series Control Electronics and Partner Torsion Software.

Instron MT Series Low Capacity Torsion Testing System

Dual linear slide design provides high-rotational stiffness and low-axial friction
Adjustable crosshead locking system allows crosshead to be free-floating or fixed during testing
Interlocked test space enclosure enhances operator safety

Digital control electronics allow for accurate and repeatable test results and fast control response for both torque and angle
Torsion testing software offers easy test set up, graphical data plots, automatic calculation of desired test results and flexible reporting tools
Torque Cell protection device minimizes the chance of over-ranging low capacity torque cells during test set up
Optional axial preload assembly applies a constant tensile or compressive load during test
Range of low-capacity torque cells are available down to 0.225 Nm (2 lbf-in)
Designed and sized to easily fit on a lab table top
Offered in 2 model types: - MT1 with 22.5 Nm (200 lbf-in) Maximum Torque Capacity and 120 RPM maximum test speed - MT2 with 225 Nm (2000 lbf-in) Maximum Torque Capacity and 60 RPM maximum test speed
Brochure: Yes – PDF *Website*: http://www.instron.us/wa/product/MT-Series-Low-Capacity-Torsion-Testers.aspx

5.2.5.3 Multi-Axial

Multi-axis testing systems provide the ability to more closely simulate the real-life performance of various parts and components. These systems are designed to apply forces and deformations in more than one axis. The ElectroPuls™ E1000 from Instron is a state-of-the-art electrodynamic test instrument designed for dynamic and static testing on a wide range of materials and components from static and fatigue testing of spinal segments to stent fatigue testing to orthopaedic fixation device testing.

Instron ElectroPuls E1000 Materials Testing System

Patented, oil-free linear motor technology for clean conditions
Designed for both dynamic and static testing on a variety of materials and components
High dynamic performance, capable of greater than 100 Hz operation
±1000 N dynamic load capacity and ±710 N long-term static load capacity
Electrically powered from single phase main supply, no need for hydraulic or pneumatic air supplies
Temperature-controlled air-cooling system
High stiffness, precision-aligned twin column load frame with actuator in upper crosshead
Versatile T-slot table for regular and irregular grips and specimens
Compact instrument - frame requires less than 0.15 m² (1.6 ft²) of desk space
Brochure: Yes – PDF *Website*: http://www.instron.us/wa/product/ElectroPuls-E1000-All-Electric-Instrument.aspx

5.3 Virtual Modeling

5.3.1 Analytical Biomechanics – Hand Calculations

5.3.2 Digital Human with Force and Torque Outputs

5.3.2.1 Siemens PLM – JACK

Jack is a human modeling and simulation tool that enables you to improve the ergonomics of your product designs and to refine industrial tasks. Jack, and its optional toolkits, provides human-centred design tools for performing ergonomic analysis of virtual products and virtual work environments. Jack enables you to size your human models to match worker populations, as well as test your designs for multiple factors, including injury risk, user comfort, reachability, line of sight, energy expenditure, fatigue limits and other important human parameters.

100s of options, body dimensions taken from anthro databases – 5th to 95th percentile, male female, etc
User can set posture, dynamic motion, and get output desired.
Static and dynamic simulation - generated by key framing, task simulation. Also possible to generate via motion capture (e.g. data gloves)
Static and Dynamic output - any joint under different loading conditions
High Fidelity
Basic Jack: $26.5K + 4K per year "Fully loaded" Jack with all toolkits: Approx $50K

Motion Capture Toolkit: $16K plus 2.5K per year Task Analysis Toolkit: $10.6K plus 1.6K per year
The advantage to Jack is the ability to create models and do many (generic) biomechanical tests with standalone software that doesn't require the software company to develop it. Able to evaluate strength requirements for many dynamic tasks. There is also a motion capture toolkit.
Superior hand model – hand anthropometrics, joint definitions. Therefore less chance for error when completing hand clearance studies.
Website: http://www.plm.automation.siemens.com/en_us/products/tecnomatix/assembly_planning/jack/index.shtml?&ku=true&a=0 Brochure? Yes - pdf

5.3.2.2 Santos

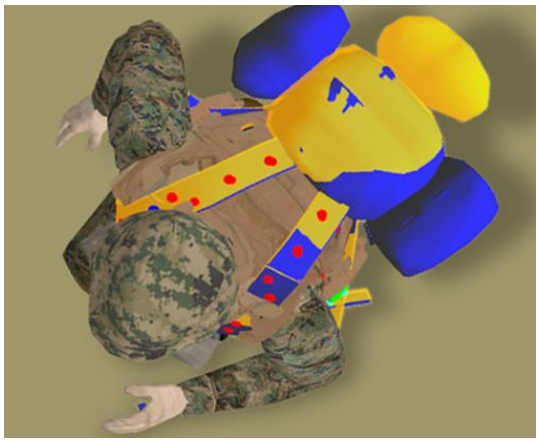
SantosHuman is a human modeling technology that predicts human posture and motion for avatars in a physics-based 3-D environment. Constraints include gravity, muscle fatigue, muscle strength, clothing fit, material properties and use of predictive dynamics.

Anthropometry: 12 body sizes, 1 female. "Infinite variable anthropometry" is advertised but the validity of outputs (e.g. force/torque) is unknown when user-adjusted.
Posture and dynamic motion is generated through "predictive dynamics" "inverse dynamics" and "created or 'tweened' between static postures or motion capture"
Outputs can be forces and moments of any joint, static or dynamic.
High Fidelity.
$ N/A – depends on the application required and how they set it up.
Not standalone software - requires Santos Human Inc. to develop it for your particular application
Advanced hand model: 25 DOF hand definition for grasping motions. Advanced clothing module.

Special patent for posture prediction.
The advantage to Santos is that they will accept funding to develop the application for a specific need. Santos is unique because it has a physics engine *and* a unique optimization-based approach to motion prediction. However, the optimization for motion prediction is not validated.
Website: http://www.santoshumaninc.com/ Brochure? Yes - pdf

5.3.2.3 Boston Dynamics – Digital Biomechanics

Digital Biomechanics is simulation tool to model the effect of equipment on soldiers engaged in actual tasks, from walking, running, and crawling to completing a virtual obstacle course. These human models obey the same laws of balance, locomotion, and dynamic loading as real people do in the physical world. Digital Biomechanics predicts how changes in equipment, environment or task will affect soldier performance, bodily forces, and fatigue during realistic warfighting tasks. It is used to analyze soldier performance before building physical mock-ups and doing live testing.



2 anthropometric options (based on the two participants who were used in motion tracking for input to the simulation). Both are male.
Dynamic motion is generated by what the programmers have created – a software user cannot develop their own scenarios. Gravity and various pieces of military equipment (e.g. rifles and backpacks) are applied to the model along with the motion which has been generated through a motion tracking system on a real participant.
Outputs can be force or torque for specific joints that the Boston Dynamics have chosen for a particular simulation. (e.g. a rifle manipulation from "ready" to "aim" position allows for torque output in the lower back). Outputs can also be ROM.
$80K + 15-30K to get a new application developed
The advantage to Digital Biomechanics is that they already work in the military domain and will accept funding to create a simulation for a specific need.

Website: http://www.bostondynamics.com/bd_digitalbiomechanics.html Brochure? Yes - pdf

5.3.2.4 MADYMO

MADYMO (MAthematical DYnamic Models) is impact biomechanics software for analysing and optimizing occupant safety designs.

MADYMO Solver

The MADYMO Solver is a flexible multi-physics simulation engine that uniquely combines the capabilities of multibody (MB), finite element (FE) and computational fluid dynamics (CFD) in a single solver. This makes the MADYMO Solver a highly efficient tool for design and analysis of complex dynamic systems.

MADYMO Dummy Models

Years of research and development has led to the creation of the most extensive database of crash test dummy models available. MADYMO Dummy Models are famously accurate and also renowned for their computational speed, robustness and user-friendliness.

MADYMO Human models

The human body models offer improved biofidelity and can be used in many applications in the areas crash safety, personal protection, sports injuries and seating comfort. The latest development activities are focussed around implementing active muscle modelling.

MADYMO Workspace

MADYMO Workspace is a suite of pre- and post-processing applications for the creation and modification of MADYMO models and for analysis of the simulation results. The applications contain dedicated tools for occupant restraint analysis such as a seatbelt fitting module and automated extraction of NCAP star ratings.

MADYMO Coupling

MADYMO can be interfaced with the FE structural codes LS-DYNA, PAM-CRASH, RADIOSS and ABAQUS. This enables engineers to use MADYMO features that are not available or do not have the required capabilities in their preferred FE code, like the MADYMO quality dummy models and airbag deployment modelling techniques.

Anthropometry: Approx 50 crash test dummies are modelled: Frontal, side, rear, child, impactors, aviation, motorcycle. Also human models are available with scalable anthropometry.
Impact injury prediction and modeling based FEA and other physics engines in virtual reality.
Dynamic simulation - generated by applying impact force in an automobile, generated by crash test and vehicle safety data.
Dynamic output - impact injury calculation
High Fidelity
Cost: $15K plus yearly subscription
The advantage to MADYMO is the ability to predict impact injury - especially in the automotive crash test environment.
Website: http://www.tass-safe.com/en/products/madymo/ Brochure? Yes - pdfs

5.3.2.5 Dassault – Delmia Virtual Human (formerly Safework)

Digital human modeling technology can assist a designer in determining the performance of people in the context of a workplace, or their interaction with a product throughout its entire lifecycle, from conceptual planning through to final decommissioning before the product exists.

Human Builder

Human Builder permits the intuitive creation and manipulation of accurate standard digital humans for initial worker/product interaction analysis. Human Builder offers a user-friendly interface and ensures that first level Human Factors studies can be undertaken by non-Human Factors specialists. Simple pull-down menus are used to create male and female standard manikins. (Name, Gender, 5th, 50th, 95th percentile.) The sophisticated manikin structure consists of 99 independent links, segments and ellipses. In addition, the manikin possesses fully articulated hand, spine, shoulder, and neck models to accurately reproduce natural movement, which includes seven default inverse kinematics for manikin motion.

Human Task Simulation

DELMIA Human Task Simulation is a powerful simulation tool used to create, validate, and simulate activities for "workers" using the DPM planning and simulation infrastructure. Workers perform these activities within the PPR

environment where they may walk to a specific location, walk up and down stairs, ascend and descend ladders, move from one target posture to another, follow the trajectory of kinematics devices or path of an object, or automatically grasp and pick and place parts in the work area. Users can also establish part relations to constrain specific segments of the worker to parts or tools in its environment. Position constraints are also stored from selected segments to selected 3D objects in the environment or standard V5 catalogs. Those constraints are subsequently solved to update the posture the next time the activity is modified.

DELMIA Virtual Ergonomics can be combined with DELMIA's DPM Assembly to analyze the relationship between workers and other entities within the simulation. They can be simulated and validated using the powerful process simulation and capabilities within DPM, allowing the user to test and optimize multiple alternatives for the work humans must accomplish in a specific manufacturing, maintainability, and assembly environment.

Human Activity Analysis

Human Activity Analysis allows the user to maximize human comfort, safety, and performance through a wide range of advanced ergonomics analysis tools and standards that comprehensively evaluate all elements of a worker's interactions with a workcell. DELMIA's advanced human activity tools specifically analyze how a worker will interact with objects in the virtual environment. Users can accurately and efficiently predict human performance, ensuring conformance to factory standards and maximizing performance. DELMIA Human Activity Analysis includes a wide range of ergonomics tools for analyzing worker performance such as:

- 3D biomechanics analysis tools to calculate torques, loads, and shear
- Analyzes lifting, lowering, and carrying tasks using NIOSH 81 and 91 equations
- Evaluates push and pull tasks using the SNOOK and CIRIELLO equations
- RULA for arm position assessment, with the ability to customize RULA specifications

Human Posture Analysis

Human Posture Analysis permits the user to quantitatively and qualitatively analyze all aspects of a worker's posture. Whole body and localized postures can be examined, scored, and iterated to determine worker comfort, safety, strength, and performance when interacting with a product in accordance with published comfort databases. User-friendly dialogue panels provide postural information for all segments of the manikin and color coding techniques ensure that problem areas can be quickly identified and iterated to optimize posture. Expert users can share their knowledge by saving ergonomics criteria, posture preferred angle, degree of freedom (DOF), and range of motion inside a user-defined catalog. This valuable information can be made available throughout the enterprise.

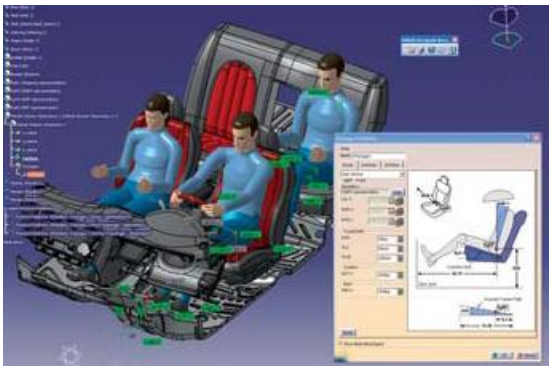
- Provides lock/unlock DOF
- Displays, defines, and manipulates joint limits in terms of comfort, strength, and safety
- Scores postures according to the preferred angles zones
- Finds best posture automatically
- Supports published comfort databases for postural analysis
- User-defined comfort and posture databases

Human Measurements Editor

Human Measurements Editor allows the creation of advanced, user-defined manikins via a suite of advanced anthropometry tools. Manikins can then be used to assess the suitability of a product or process against its intended target audience. Upon user input of appropriate critical design variables, a multi-normal statistical algorithm automatically adjusts all other anthropometry variables to create manikins that exist within a target publication. This unique "boundary" manikin technique ensures that designers accommodate their entire target population using a minimum number of manikins. The intuitive Graphical User Interface (GUI) permits designers to analyze the functional relationships between anthropometry variables. In addition, the user can define task-related critical values for detailed investigation while Human Measurements Editor determines the values' remaining variables

Vehicle Occupant Accommodation (VOA) provides a set of tools enabling to reduce the number of physical prototypes, minimize customer focus groups and reduce the number of design iterations required to ensure an interior vehicle design that meets the occupants needs in term of comfort and accommodation. Vehicle Occupant Accommodation (VOA) allows companies to explore, compare and validate more design alternatives by letting 3D information accessible to all stakeholders. VOA enables organizations to:

- Automate elements of vehicle occupant packaging process
- Increase productivity of vehicle occupant packaging analysis
- The rapid preparation of review sessions in a continuous product quality assessment process
- Leverage enterprise intellectual property and proprietary knowledge
- Effectively predict vehicle occupant posture



100s of options for anthropometry, body dimensions taken from ANSUR
User can set posture, dynamic motion, and get output desired
Static and dynamic simulation – motion generated by translating from one post to the next
Range of Motion, Field of View, Muscular activity, energy expenditure
High Fidelity
Potentially multiple humans in one simulation

$15K to 50K depending on configuration
Standalone software – the software user is able to generate inputs/motion/outputs
Website: http://www.3ds.com/products/delmia/solutions/human-modeling/ Brochure? Yes - pdf

5.3.2.6 Ramsis

RAMSIS is the standard solution for designing vehicles and aircraft from an ergonomic standpoint. This leading CAD manikin enables efficient analyses covering the topics of vision, comfort and ergonomics based on a globally unique anthropometric database. RAMSIS also integrates itself in Catia, eM-Human and Virtual Reality systems.

RAMSIS Automotive is used by more than 70 percent of all car manufacturers. CAD manikin fields of application range from the ergonomic design of driver and passenger areas to vehicle design for efficient maintenance and repair work.

RAMSIS Industrial Vehicles facilitates the ergonomic development of commercial vehicles like heavy machinery, construction vehicles and wheel loaders. Analysis and optimization with RAMSIS vastly improves the levels of safety for drivers and persons in the vicinity of the vehicle - and maintenance work can be carried out much more simply.

RAMSIS Bus & Truck ensures more comfort and safety in the driver's workplace. Ergonomic design reduces signs of fatigue and absences from work due to illness - thus increasing driver efficiency.

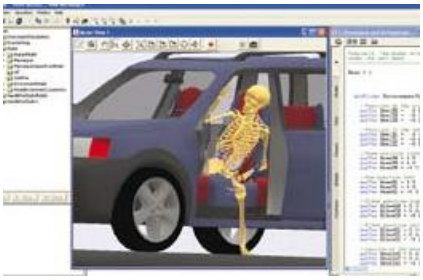
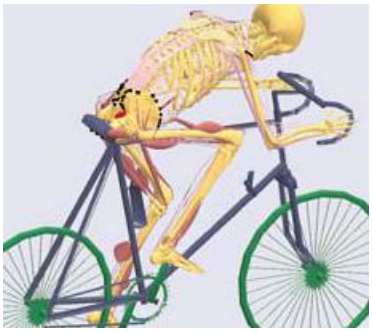
RAMSIS Aircraft is used for a wide range of aircraft-associated tasks - from the ergonomic design of cockpit and passenger areas to feasibility studies relating to the serviceability of the aircraft.

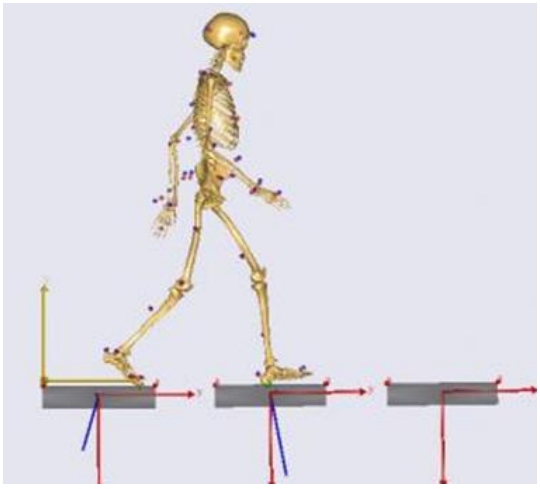
ANTHROSCAN enables the efficient planning and execution of anthropometric serial measurements for individual market segments and national/international markets.

100s of options for anthropometry, body dimensions taken from a globally unique anthropometric database
User can set posture, dynamic motion, and get output desired
Static and dynamic simulation
Comes from German car industry. Unique vision analysis: readability, reflection/glare. Unique reachability analysis: user defined comfort reach envelopes.
Vision, comfort, and ergonomics analysis. Specialized for vehicle seating positions and operation of vehicle controls. Automatic posture calculation. Works directly with 3D scanner (Vitus Smart by Human Solutions)
High Fidelity
Potentially multiple humans in one simulation
$28,500 for base software up to $50,000 with vision / force analysis options (some specific to automotive applications)
Standalone software – the software user is able to generate inputs/motion/outputs
Website: http://www.human-solutions.com/automotive/products_en.php Brochure? No

5.3.2.7 Anybody

The AnyBody Modeling System™ is a software solution for simulating the mechanics of the live human body working in concert with its environment. The environment is defined in terms of external forces and boundary conditions, and the user may impose any kind of posture or motion for the human body - either from scratch or from a set recorded motion data. AnyBody then runs a simulation and calculates the mechanical properties for the body-environment system.
From AnyBody the user can obtain results on individual muscle forces, joint forces and moments, metabolism, elastic energy in tendons, antagonistic muscle actions and much more.
AnyBody can also scale the models to fit to any population from anthropometric data or to any individual. Or, you can parameterize your studies in AnyBody to match product design trade-offs, finding the optimum combination of parameters to fulfill a given purpose.



1000+ muscle elements (high fidelity), models can be scaled to fit any population from anthropometric data.
User can set posture, dynamic motion, and get output desired. Also allows import data from motion capture systems.
Static and dynamic muscle/joint simulation. AnyBody does not perform vision and reach analysis or import/export CAD files. It can import motion data in C3D format.
Static and Dynamic output - any joint or muscle under different loading conditions
High Fidelity for musculoskeletal system
$34K + 6K per year
The advantage to AnyBody is a focus on the musculoskeletal system in a high fidelity way, with standalone software that doesn't require the software company to develop it.
Website: http://www.anybodytech.com Brochure? Yes - pdf

5.3.3 Digital Human with ROM / Spatial Outputs

5.3.3.1 HumanCAD (Formerly Mannequin Pro)

ManneQuinPRO has been superseded by HumanCAD in May 2007. HumanCAD is a human modeling solution that creates digital humans in a three-dimensional environment in which a variety of ergonomic and human factor analysis can be performed. HumanCAD aids users with the design of products and workplaces by determining what humans of different sizes can see, reach or lift.

It is a lower-fidelity human modeling package that does some limited animations but does not have physics engine for force/torque outputs during dynamic simulations.

Flexible Anthropometry

•Extensive anthropometric databases of men, women and children including 1988 Natick US Army and NASA-STD-3000

•Semi-auto control for anthropometry: The height and weight values for a model can be entered manually, while the remaining body segments are scaled accordingly

•Manual control for anthropometry: Individual body segment dimensions can be entered manually to generate a specific anthropometric model

Easy Mannequin Positioning

•Completely articulated body within human ranges of motion

•Library of pre-defined mannequin body and hand postures

•Real-time Inverse kinematics (IK) and forward kinematics (FK)

•Mannequin reach to selected point

•Digital floor with manikin snap-to-floor feature

Ergonomics and Space Analysis

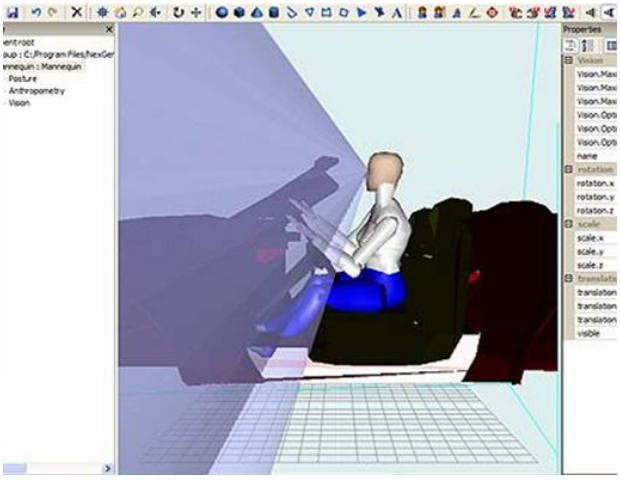
•Reach-envelopes for hands and feet

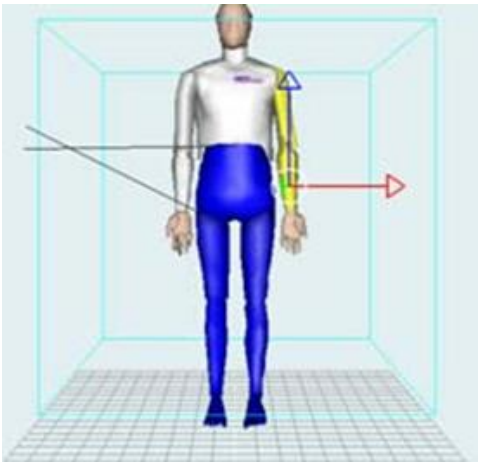
•Manikin's vision analysis with vision view windows, 3D representations for field of view, vision cones

•Basic 2D and 3D drawing/modeling tools including annotation and markup

•Dynamic distances and angles: Measurements are updated automatically when the 3D scene changes, for example as parts move or manikins are resized.

•Optional ErgoTools includes the revised NIOSH Lifting Equation and multiple biomechanical model options (including an interface to the University of Michigan 3D SSPP model)

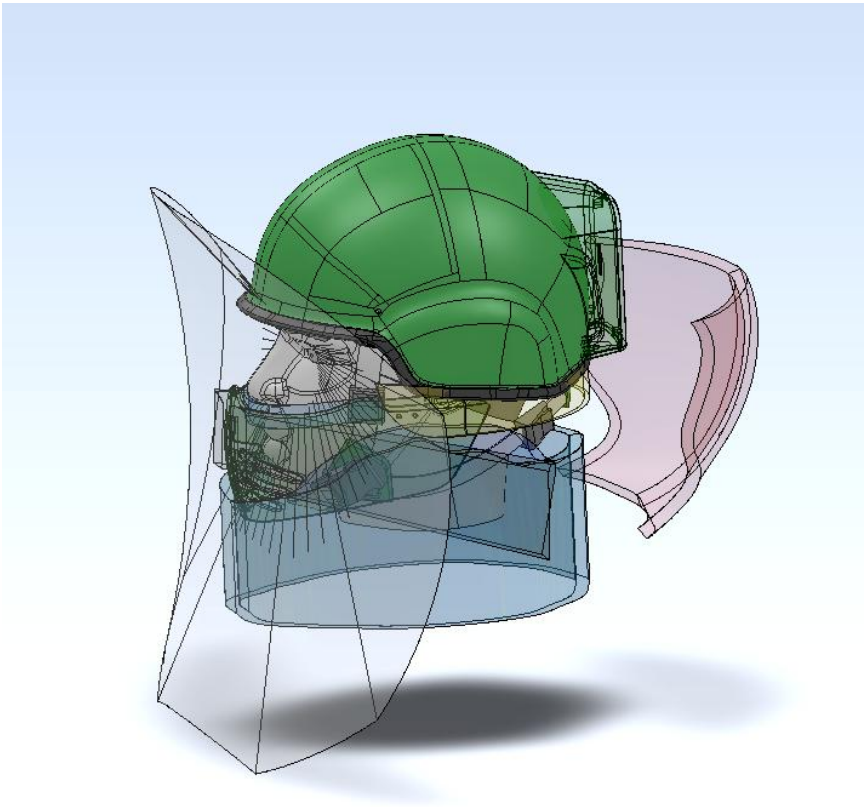




Anthro: Extensive anthropometric databases of men, women and children including 1988 Natick US Army and NASA-STD-3000
User can set posture and get output desired such as ROM, FOV, static forces and torques
Some limited animations but no physics engine to derive real-time force/torque outputs
Medium Fidelity
$10K
The advantage to HumanCAD is a lower expense that doesn't worry about dynamic outputs. SolidWorks and other 3D parts can be imported and the appropriate spatial analyses can be made (ROM, FOV)
Website: http://www.nexgenergo.com/ergonomics/humancad.html Brochure? No

5.3.3.2 SolidWorks

SolidWorks is one example of a 3D CAD modeling software package. While not intended specifically for virtual modeling of digital humans, some amount of analysis can be done by bringing solid parts of digital humans into the virtual space and analysing the interaction with equipment. Analyses can include ROM and FOV as well as equipment compatibility.

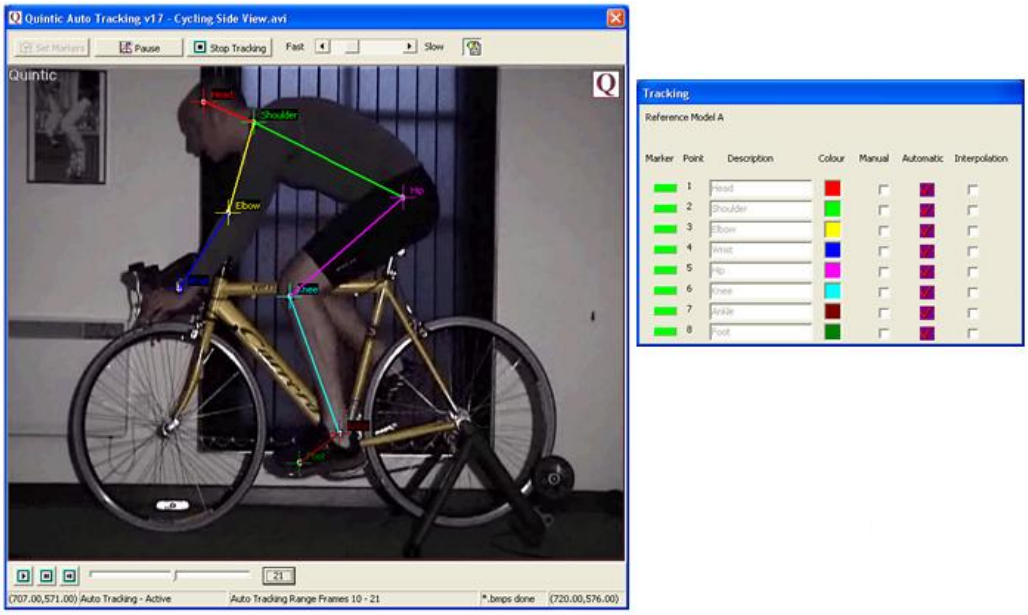


Anthropometry: No human database exists, but any kind of part can be imported. Some headforms exist in libraries and other human models can be downloaded for $400-600, although the validity of such models is unknown.
User can set posture in 3D space. Output would be limited to spatial analysis.
High Fidelity parts but low fidelity analysis.
$6000 + $1500 per year
The advantage to SolidWorks is the ability to import industry-standard parts/workstations. The HumanCAD software works well with SolidWorks.
Website: http://www.solidworks.com/ Human model libraries: http://www.zetec.co.nz/bodyworks/ www.human2go.com/

Brochure? No

5.3.4 Video Analysis for Time and Motion Studies

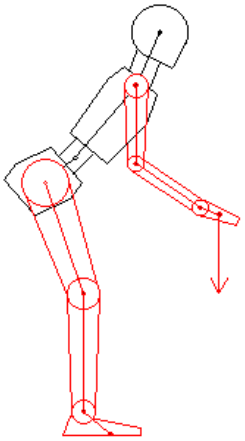
5.3.4.1 Kinematic Analysis Software

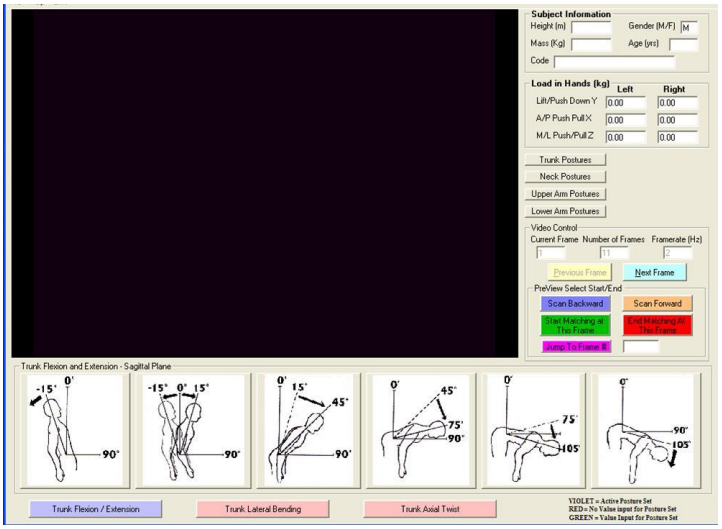


Kinematic Video Analysis software packages are designed for the elite coach, elite athlete, sports scientist, podiatrist, physiotherapist or biomechanist. They provide rapid feedback from recorded video and allow analysis of dynamic motion patterns, potentially awkward joint postures, and inconsistent movement in repeated trials in athletic, laboratory or occupational tasks. Typical features include: split screen analysis, drawing tools, angle measurement, video overlay, automatic digitization, distance calibration, event markers, and kinematic (distance, velocity and acceleration) calculation. For biomechanists, the automatic digitization allows for full 2D motion tracking and marker position recording. Tracked marker data can be easily exported to TXT or CSV format for further biomechanical analysis. These software packages do not offer the accuracy and functionality of 3D motion capture systems, but provide a reliable, effective, and economical solution ideal for elite coaches and athletes as well as biomechanists and kinesiology students
$4000 for a Quintic Biomechanics annual liscence
Advantage: various freeware video editing software packages are available (eg. VideoMach, www.gromada.com).
Disadvantage: the software tool required is highly dependent on the needs of a specific project. A video editing software package is most often needed for video conversion, breaking digital video into still images, or down-sampling video to a required frame rate in

preparation for analysis.
Manufacturer: Kinovea Website: http://www.kinovea.org/en/ Manufacturer: Quintic Biomechanics Website: http://www.quintic.com/ Brochure? No

5.3.4.2 2D Biomechanical Analysis Software





Biomechanical Analysis software packages offer similar functions to the Kinematic Analysis software, but generally have the ability to calculate acute and cumulative loads at the major body joints, particularly the lumbar spine region. They can be used to estimate the risk of injury associated with a variety of occupational actions including pushing, pulling, lifting, lowering, holding, or carrying. Inputs are gender, anthropometric measures, load characteristics, time characteristics, and 2D (X, Y) coordinates of the major body joints. These 2D coordinates are generated from a kinematic analysis software package or a more advanced motion tracking system. These tools are generally simple to use and can output measures such as acute lumbar moment, compression, reaction shear, joint shear, and pain reporting (injury risk) classification based on these measures. Such software packages are typically developed by academic institutions and may or may not be released or sold for public use.
Examples of such software packages include 4DWatbak (McGill and Norman, 1986) and 3DMatch (Callaghan, 2003), both developed at the University of Waterloo. Limited commercially available 2D Biomechanical Analysis software packages exist.